STUDIES ON COLIFORM BACTERIA DISCHARGED FROM THE HYPERION OUTFALL

FINAL BACTERIOLOGICAL REPORT

by

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Introduction

A previous report entitled "The Fate of Coliform Bacteria in the Vicinity of the Orange County, Los Angeles County, and Hyperion Sewer Outfalls, May 1, 1956"[1] dealt with the bacteriological data collected between September 1955 and March 1956. Subsequently, six additional trips were scheduled to obtain the additional information required before final conclusions could be drawn. This report presents only the new data, but the discussions and conclusions are based on all of the available bacteriological information, including that in the previous report. Consequently, the May 1 report should be considered an integral part of this final report.

Of the six trips made, two were concerned with the collection and analysis of coliforms in sediments from the Orange County and Santa Monica Bay areas. The remaining four trips were in Santa Monica Bay during periods when unchlorinated primary effluent was being discharged from the Hyperion outfall. On one trip a radioactive tag was added to the effluent at the plant to serve as a tracer. The data from this trip are presented first out of chronological order because of their significance in substantiating the validity of other types of information collected.

No description of field or laboratory methods are included in this report unless they differ from those described in the May 1 report.

1. Referred to in the text as the "May 1 report".

COLIFORM BACTERIA IN THE WATER

Radioactive Tracer Study

Description of Cruise

On the day of the tracer experiment, unchlorinated effluent was discharged from the Hyperion plant for a total of eight hours, according to the following schedule: unchlorinated secondary, three hours; unchlorinated primary, two hours; unchlorinated primary with tag, one hour; unchlorinated primary, one hour; unchlorinated secondary, one hour. Radioactive scandium-46 was fed into the primary unchlorinated effluent at the treatment plant at a constant rate for one hour starting at 0700, May 23, 1956. Sufficient scandium-46 was introduced to allow a measurement of dilution of the effluent to about one part in 10,000.

Radioactivity was detected in the boil approximately one hour after its introduction into the outfall, and measurements were continued in the boil for a further hour until the radioactivity started to decrease. Two dye patch experiments were started, about one hour apart, while the radioactivity was at its peak. A series of patterns, spaced at appropriate intervals, was then traversed by the VELERO IV making radioactivity measurements while underway. These patterns served to delimit the extent and position of the radioactive field at various times. Surface samples were taken while the ship was underway at positions where the radioactivity appeared maximum. At the end of each traverse pattern, the ship returned to the position of maximum radioactivity where measurements were taken of radio-

activity vertically through the water column, and subsurface samples were collected for bacteriological and chemical analyses. All surface samples for bacteriological analyses (dye patch, underway, and profile stations) were collected in sterile one gallon jars and the identical samples were also used for measurements of radioactivity and chlorinity.

A description of the equipment used, the method of calculating dilutions, and the data showing the position and intensity of the surface and subsurface radioactive fields at various times is given in the report of the Nuclear Science and Engineering Corporation, June 29, 1956.[1]

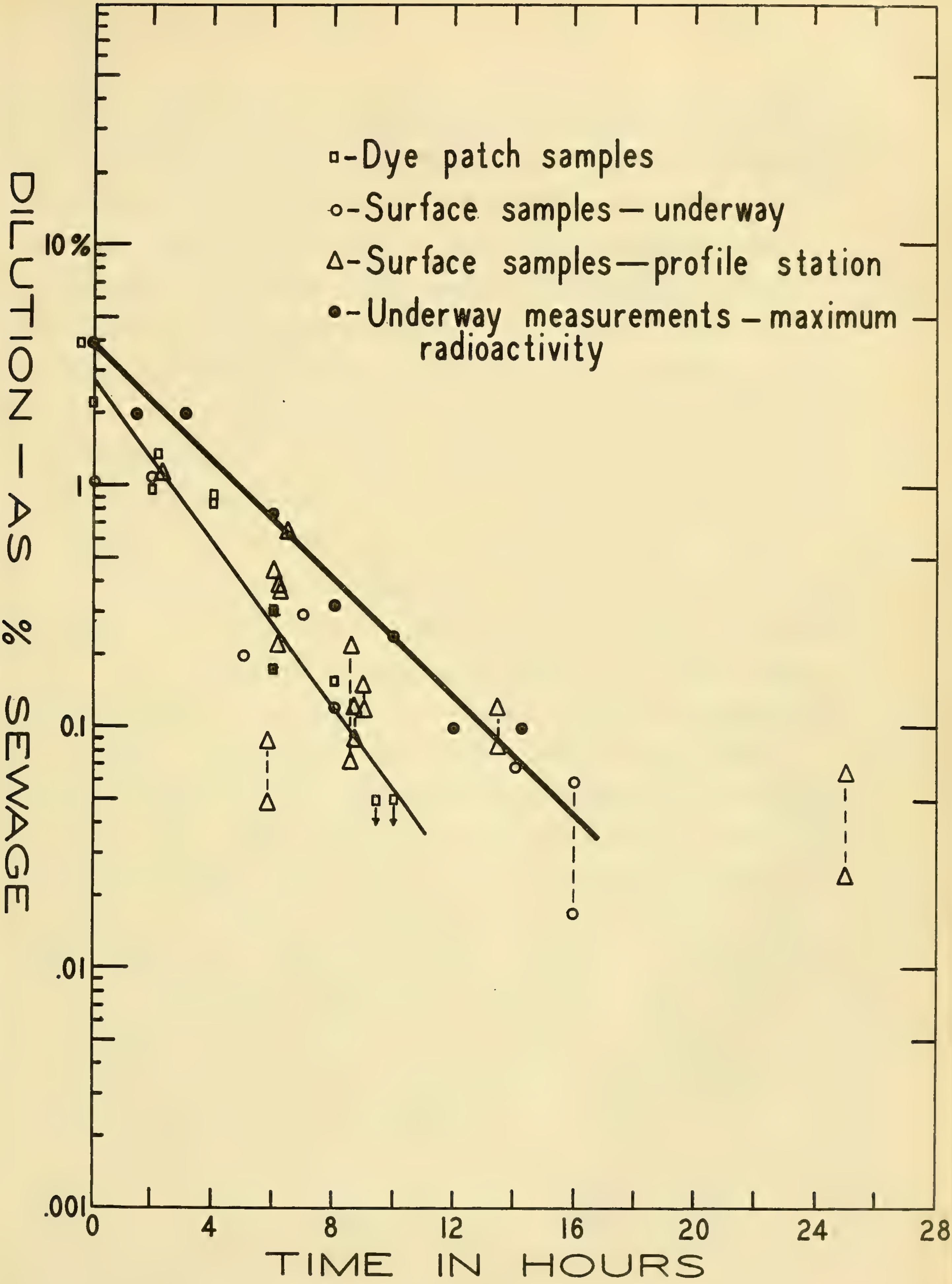
<u>Dilution of Radioactivity with Time</u>

Radioactivity was first detected in the boil at about 0747. Its intensity rapidly reached a plateau that was maintained until the VELERO IV left the boil for the first traverse pattern at 0901. During this period, dilution of the effluent as calculated from the radioactivity, ranged from 1/12.5 to 1/100 with most of the values clustered around 1/25. The observed variations were probably due in part to the VELERO IV moving in and out of the boil during measurements, and in part to variations in the rate of feed of the tracer into and mixing with the effluent. The initial measurements on the subsurface radioactivity showed that essentially all of the tagged effluent rose to the surface of the ocean at the point of discharge.

There was a consistent and fairly rapid dilution of the radioactivity as the tagged effluent field moved away from the the boil. The change with time is plotted in Figure 1 which

1. Referred to in the text as the "NSE report".

Figure 1. Dilution of sewage as determined from radioactivity.



□-Dye patch samples
○-Surface samples — underway
△-Surface samples — profile station
●-Underway measurements — maximum radioactivity
DILUTION – AS % SEWAGE
10%
1
0.1
.01
.001
0
4
8
12
16
20
24
28
TIME IN HOURS

includes data from four types of measurements. The closed circles represent the minimum dilutions (maximum radioactivity and therefore maximum effluent concentration) detected on the various underway traverses, and the upper line is the approximate best fit through these points. The squares represent the dilutions calculated from the radioactivity of the samples collected in the two dye patches, and the lower line is the approximate best fit line through these points. The triangles and open circles are dilutions calculated from radioactivity measurements on the surface samples collected underway and from the surface samples collected at the profile stations, respectively.

The main point to be emphasized, besides the marked dilution of the radioactivity with time shown by all four types of measurements, is that there is no great difference between the minimum dilution found by traversing the sewage field and that measured by following a dye patch. The dilution curves from the two types of measurements do diverge somewhat; however, the difference between the two lines at six hours (the usual length of most dye patch experiments) is only about two fold. Considering the variations that occur in the properties of the effluent being discharged, this difference would not introduce any significant error in measurements of coliform disappearance rates. It can be concluded that the dye patches represent a typical part of the sewage field and that confidence can be placed in data obtained by the dye patch technique.

Dilution Calculated from Radioactivity and Observed MPN's of Coliforms

A total of three samples were taken in the boil during peak radioactivity and these were analyzed for the MPN's of coliforms, radioactivity, and chlorinity. From these data one can calculate the original coliform density of the undiluted primary effluent. The data from these calculations are presented in Table I. The values obtained are reasonable for a primary treatment effluent, although the geometric mean of 720,000/ml is probably higher than would occur if a larger number of determinations were involved (see page 29).

From the calculated MPN of the undiluted effluent, one can calculate the expected MPN for any dilution of the effluent as measured by radioactivity. The results of such calculations are shown in Figure 2. The three lines are based on the maximum count, the geometric mean of the count, and the minimum count of Table I, respectively. On the same graph are included the observed MPN's of all the surface samples analyzed for coliforms plotted against dilution calculated from the observed radioactivity of the respective sample. It can be observed that beyond a dilution of 1/100, the majority of the samples gave a MPN well below the minimum calculated range. These data show that factors other than dilution are operating to reduce the coliform population within a relatively short time after the effluent leaves the outfall. A similar conclusion was previously reached from calculations based on chlorinity (May 1 report), where an even greater difference between observed and calculated MPN's existed. The significance of the greater difference is discussed later.

TABLE I

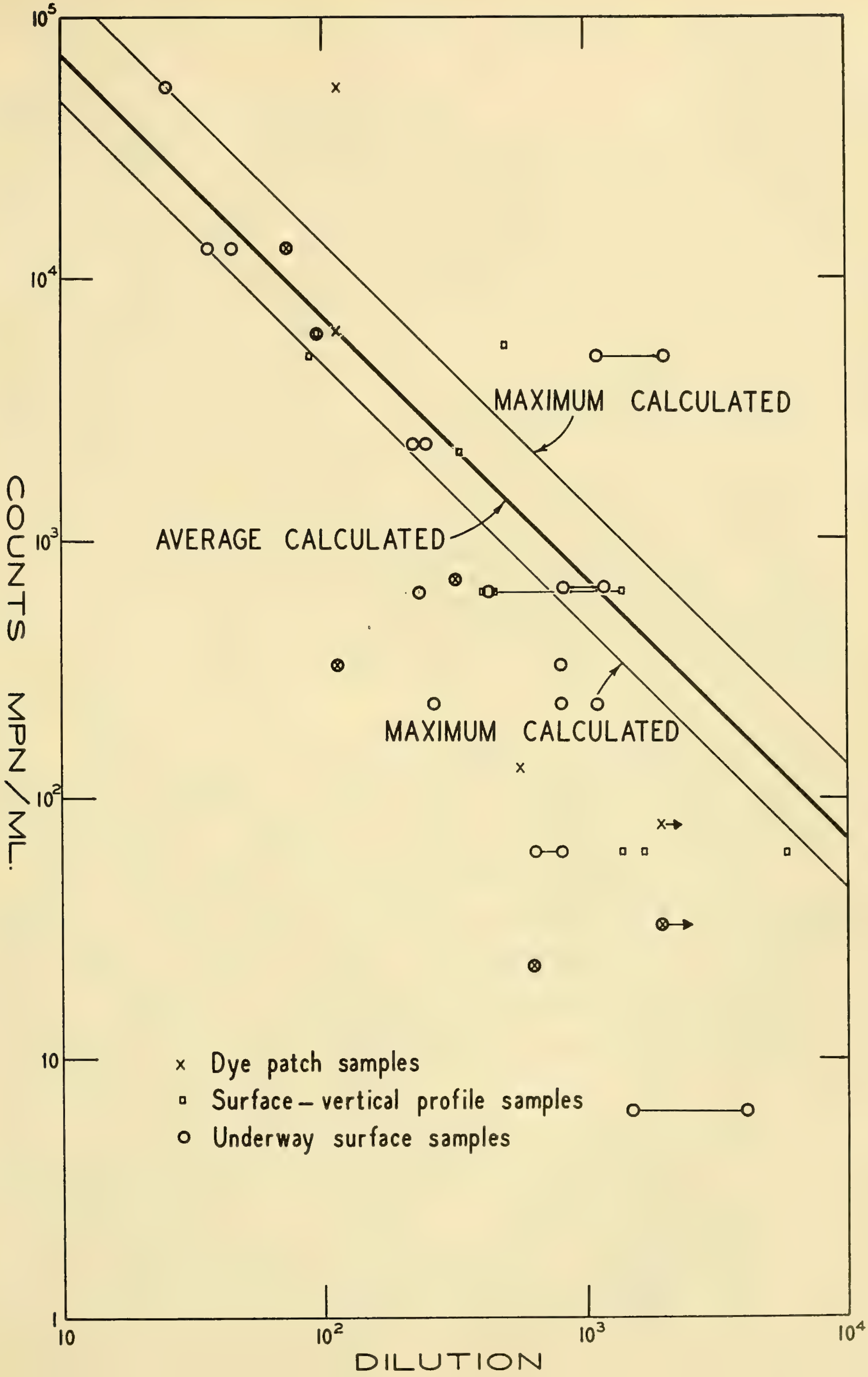
Calculated MPN's of Coliforms of the

Undiluted Primary Effluent

Sample	Coliforms MPN/ml found	Calculated dilution from chlorinity	Calculated dilution from radioactivity	MPN of undiluted effluent calculated from chlorinity[1]	MPN of undiluted effluent calculated from radioactivity
Dye patch #1	13,000	1/23	1/45	300,000	585,000
Dye patch #2	54,000	1/17	1/25	920,000	1,350,000
Station 21A	13,000	1/26	1/36	340,000	480,000
Geometric mean	21,000			450,000	720,000

1. Assumes an original chlorinity of the sewage of 0.26 o/oo and a normal chlorinity of undiluted sea water in the area of 18.60 o/oo.

Figure 2. Calculated MPN for various effluent dilutions as measured by radioactivity.



10^5
10^4
10^3
10^2
10
1
10
10^2
10^3
10^4
COUNTS MPN / ML.
DILUTION
MAXIMUM CALCULATED
AVERAGE CALCULATED
MAXIMUM CALCULATED
x Dye patch samples
▫ Surface – vertical profile samples
o Underway surface samples

Disappearance of Coliforms with Time

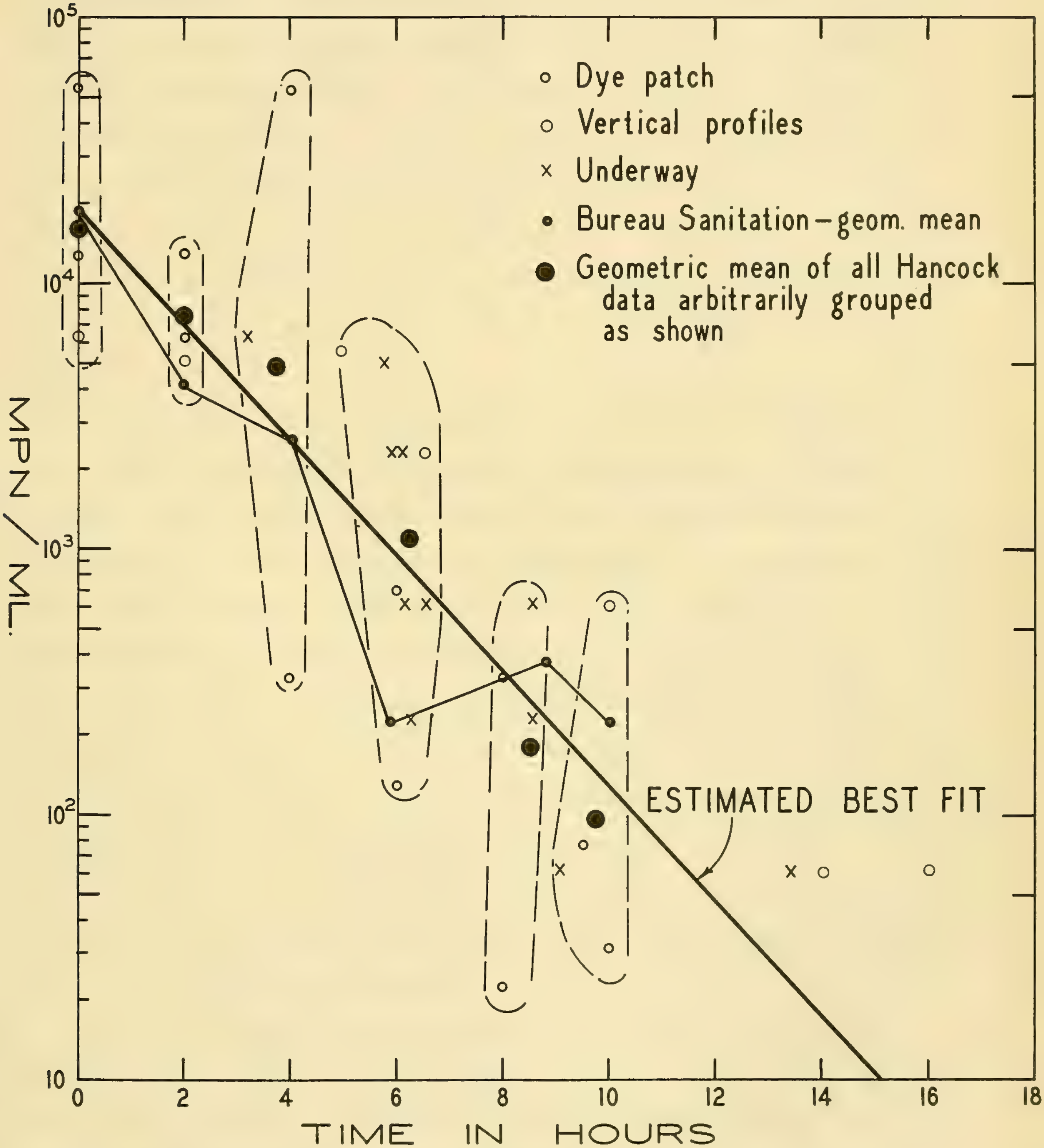
The MPN's of coliforms for all surface samples are plotted against time in Figure 3. The straight line is an approximate best fit line drawn through the geometric means of the data grouped somewhat arbitrarily as shown on the graph. The line joining the geometric means of the data collected on the same day by the Bureau of Sanitation, Los Angeles, is also shown on the graph. These data provide the best estimates of the rate of coliform disappearance on the day of the tracer experiment. It is obvious that there is no significant difference between our data and that obtained by the Bureau of Sanitation. The average rate of decrease of MPN is of the order of one magnitude (90%) every 4 to 4½ hours and the average count reduces to below ten in about 15 hours.

On the day of the trip, the sewage field instead of consistently moving away from the outfall doubled back on itself while showing a net movement towards the beach (see NSE report). It is possible under these circumstances that the coliform population of the tagged effluent was reinforced by contributions from younger effluent, and this could account in part for the terminal decrease in disappearance rate shown by the Bureau of Sanitation data, and the three relatively high MPN's obtained by us between 13 and 16 hours.

Relation between Dilution Calculated from Chlorinity and Radioactivity

The data in Table I show that a significantly greater dilution of the effluent is found when one calculates this value from radioactivity measurements as compared to values calculated

Figure 3. The MPN's of coliforms for all surface samples versus time during radioactive cruise.



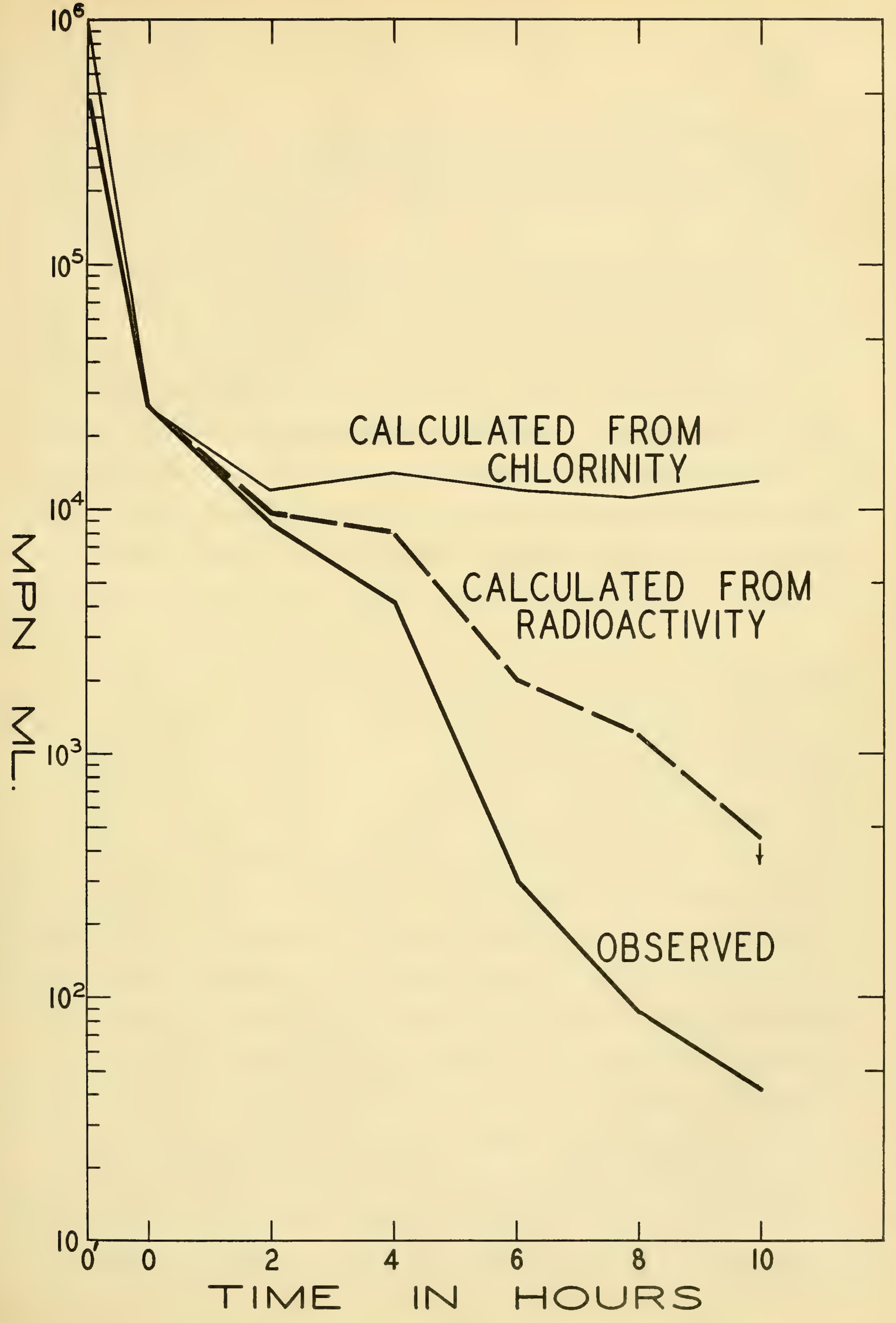
Dye patch
Vertical profiles
Underway
Bureau Sanitation – geom. mean
Geometric mean of all Hancock data arbitrarily grouped as shown
ESTIMATED BEST FIT
MPN / ML.
TIME IN HOURS
10^5
10^4
10^3
10^2
10
0
2
4
6
8
10
12
14
16
18

from chlorinity. The differences between the calculated dilutions become even greater as the effluent moves away from the boil. Using the MPN's determined for the boil samples and effluent dilutions calculated from the two types of measurements, one can calculate the MPN's for the undiluted effluent (0' sample), and for the dye patch samples taken after zero time. These data, along with the observed MPN's are plotted in Figure 4 using the geometric mean of the results from the two dye patches in all cases.

Since essentially no radioactivity existed in the area of the outfall previous to the one hour introduction of the radioisotope tag (actually the background count was determined and corrected for), the decrease in radioactivity is a measure of the total dilution of this one hour's volume of effluent. If this effluent were being introduced into undiluted sea water, then the dilutions measured by radioactivity and chlorinity would be the same. However, as is seen from Figure 4, dilutions measured from chlorinity are much less, which must mean that the tagged effluent was being diluted mainly with the untagged effluent in the area. At eight hours, for example, the tagged effluent at its maximum concentration constituted only 1/16 of the total effluent in the sample.

If the effluent field moved away from the outfall at all times, then dilution of the tagged effluent on its outer boundary would have to be with effluent of older origin and therefore lower coliform density. As previously mentioned, on the day of the experiment the tagged field curved back towards the outfall and there could have been some dilution of this field with

Figure 4. Calculated MPN's/ml from chlorinity and radioactivity versus time from outfall.



CALCULATED FROM CHLORINITY
CALCULATED FROM RADIOACTIVITY
OBSERVED
MPN ML.
TIME IN HOURS
10^6
10^5
10^4
10^3
10^2
10
0'
0
2
4
6
8
10

younger effluent. Unfortunately, the data do not permit an estimate of how much younger effluent could have been present in the samples analyzed.

In a steady state condition, with constant discharge of unchlorinated effluent instead of only two hours discharge subsequent to the introduction of the tag as was the situation, the coliform counts could have been higher than those observed and thus a slower disappearance rate would have been measured. Since the coliform count on the beach depends on the disappearance rate and the time of travel to the beach, a slower disappearance rate with a longer time of travel would have the same effect on the beach count as a more rapid rate of disappearance with a shorter time of travel.

The problem of the reinforcement of the coliform population of a particular volume of effluent by younger effluent can be examined in another way. Let us assume that a volume of effluent "A", discharged six hours before a second volume "B", has a path of travel that causes it to intersect volume "B" when the latter is two hours from the outfall. The danger of pollution on the beach would, of course, be from volume "B" and not from volume "A" in this situation. The total time of travel of "A" to "B" is 8 hours, and during this period the coliform population would be reduced by about 90% from dilution alone (Fig. 1). Volume "B", having traveled only two hours, has its coliform population reduced about 20% due to dilution alone. The contribution of coliforms from "B" to "A" is significant, but the contribution of coliforms from "A" to "B" is not, and calculated numbers of coliforms reaching the beach from "B" based on normal disappearance

rates would not differ appreciably from the actual numbers.

The extra disappearance of coliforms due to factors other than dilution is clearly seen from Figure 4. The data are strikingly similar to those obtained in the vicinity of the Orange County outfall (May 1 report, Fig. 4), except that in the latter area the calculated MPN's based on chlorinity show a slow but significant decrease with time that is not seen in the Hyperion data. The probable reason for this is that the effluent field around the Orange County outfall covers a smaller area and in most of the experiments performed the dye patches moved fairly consistently towards the perimeter of the field.

Subsurface Radioactivity Measurements

The subsurface radioactivity measurements taken at the profile stations indicate that mixing of the discharged effluent, most of which reaches the surface, eventually distributed it throughout the entire column of water in the part of the bay sampled. A qualitative inspection of the chlorinity data show that most of the subsurface water below 15-30 feet in the vicinity of the outfall is of essentially normal chlorinity, whereas the surface water for a considerable distance around the outfall contains well over 1% of the fresh water effluent (see Final Oceanographic Report). This means that all of the water in the bay is not equally effective in the dilution of the sewage and that surface currents and surface (horizontal) diffusion and mixing play the most important roles in effluent disappearance.

Using the radioactivity, chlorinity, and MPN data from the subsurface samples taken at the profile stations, one can calculate dilutions and expected MPN's as was done with the surface data. For these calculations, all subsurface samples were grouped together independent of depth or location and geometric means were calculated. For any comparisons made, only samples that were determinate for both parameters being compared were used. Thus, out of a total of 21 subsurface samples examined, ten were indeterminate for dilutions calculated either from radioactivity or chlorinity and only eleven could be used for determining the geometric means. The results obtained are presented in Table II.

The calculations do not have the same degree of validity as they do for surface samples for several reasons. First, radioactivity was measured by lowering the probe through the water column and not on the actual samples brought to the surface for coliform analysis since these samples were too small. Because of the non-homogeneous nature of the water mass and drift of the ship around the station location during sampling, the actual radioactivity of a sample could have differed greatly from that read from a depth curve. Second, dilutions of greater than about 1/300 calculated from chlorinities are certainly grossly inexact, and dilutions of greater than 1/2000 are completely indeterminate. The data presented above should be viewed with these limitations in mind.

From the data in Table II, it can be seen that a greater dilution of the tagged effluent occurs than one would calculate from chlorinity, indicating, as with the surface samples, that

TABLE II

Calculated Dilutions and Calculated and Observed MPN's of Subsurface Samples

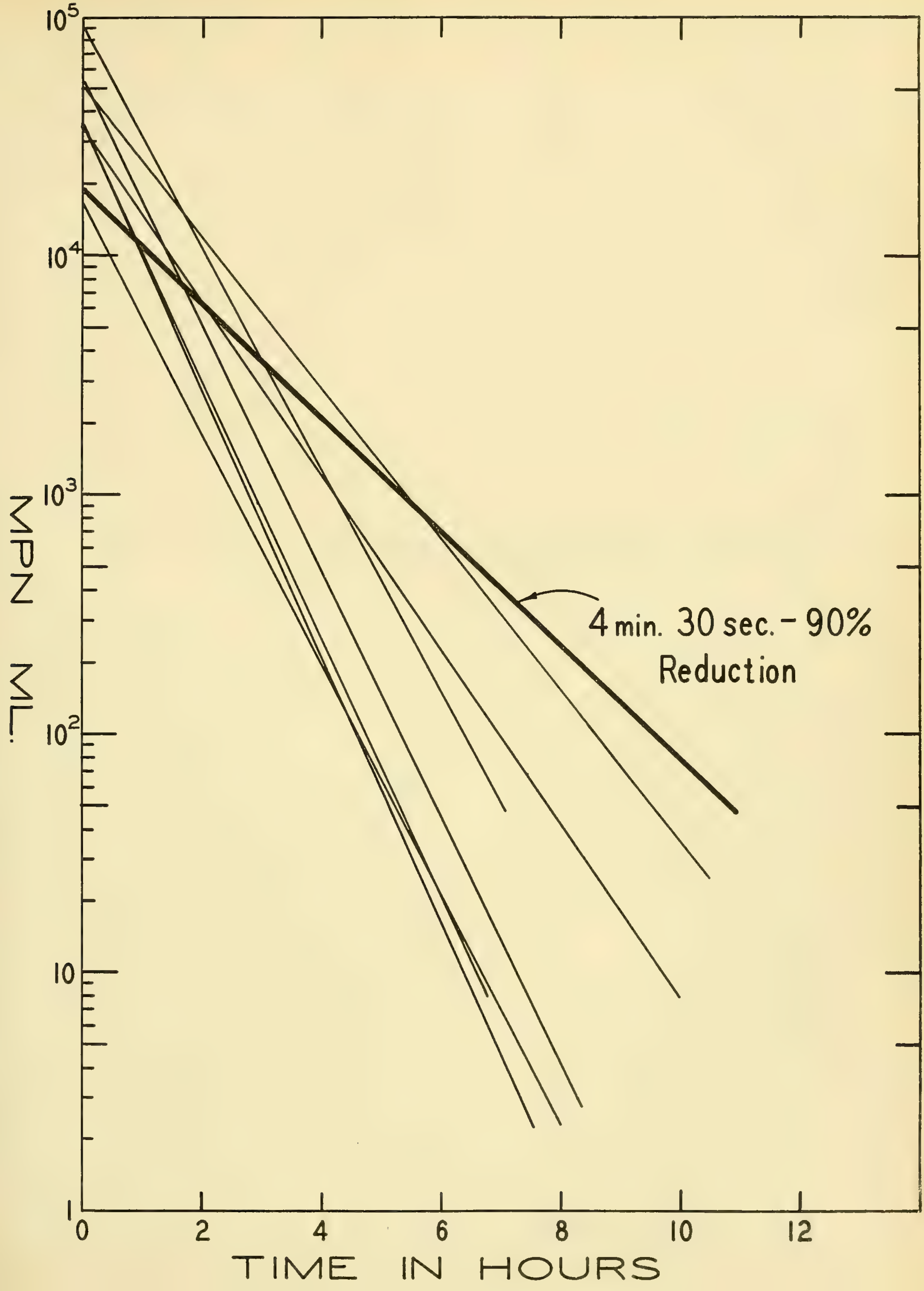
	Number of samples	Calculated from radioactivity	Calculated from chlorinity	Observed MPN's/ml.
Geometric mean of dilutions	12	1/640	1/160	
Geometric mean on MPN's/ml.	20	790		70
	11		3,600	170

dilution of fresh effluent with older effluent is occurring. The calculated MPN's are higher than the observed ones showing again an extra disappearance of coliforms in addition to that due to dilution. Assuming sedimentation to be an important factor in the extra disappearance, one might have expected the observed subsurface MPN's to be higher than the calculated MPN's, at least in some individual instances, since one might expect to trap settling particles in some of the subsurface samples. Actually, three out of the twenty subsurface samples had MPN's that were higher than the calculated, and in four instances, subsurface samples having higher counts than the water above them were observed. These limited observations provide some evidence for the occurrence of sedimentation which was evident as a cause of coliform disappearance in the vicinity of the Orange County outfall (May 1 report).

Dye Patch Experiments

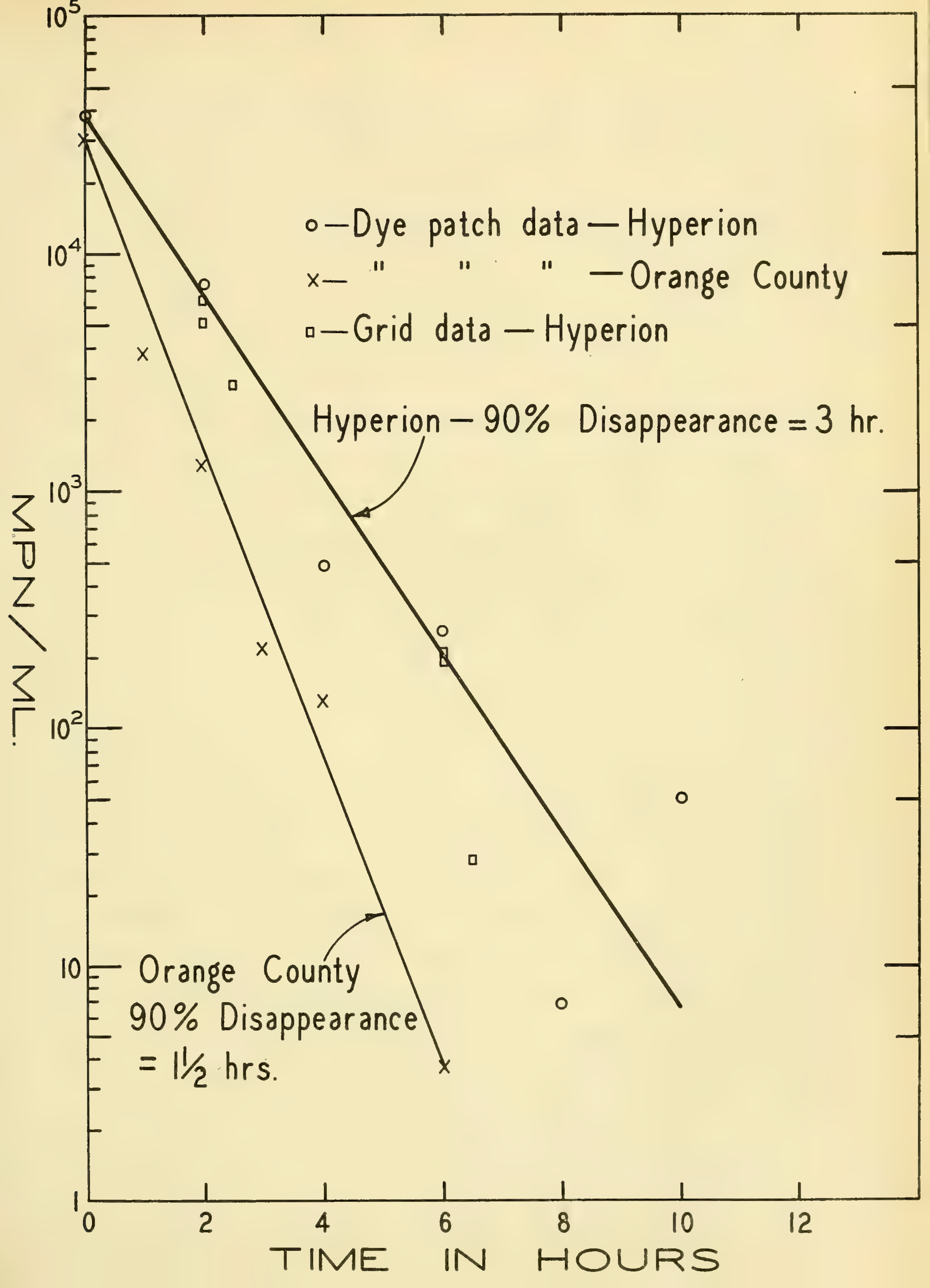
In addition to the two dye patch experiments done on the tracer cruise, six additional were run on three other trips during which primary effluent was being discharged from the Hyperion outfall. The MPN's obtained are plotted against time for each individual run in Figure 5, and the geometric means of the MPN's of all the runs against time in Figure 6. The time for 90% reduction in coliform count ranged from $1\frac{1}{2}$ hours for the most rapid to $4\frac{1}{2}$ hours for the slowest with 3 hours as the average. The last value is the best estimate available for the rate of disappearance to be expected around the proposed new outfall assuming the same type of primary effluent will be discharged.

Figure 5. The MPN of coliforms versus time for primary unchlorinated effluent.



MPN ML.
10^5
10^4
10^3
10^2
10
1
0
2
4
6
8
10
12
TIME IN HOURS
4 min. 30 sec. - 90% Reduction

Figure 6. MPN of coliforms versus time for the Hyperion and Orange County outfalls.



10^5
10^4
10^3
10^2
10
1
MPN/ML.
0
2
4
6
8
10
12
TIME IN HOURS
o — Dye patch data — Hyperion
x — " " " — Orange County
□ — Grid data — Hyperion
Hyperion — 90% Disappearance = 3 hr.
Orange County
90% Disappearance
= 1½ hrs.

The comparable data for the vicinity of the Orange County outfall are also plotted on Figure 6 for purposes of comparison, the average disappearance rate for this area being 90% in 1½ hours.

In an effort to determine whether or not the dye patch experiments gave data that were representative of the entire effluent field, experiments were run at Whites Point and at Hyperion (during discharge of secondary treatment effluent) in which a large number of samples were collected over a closely spaced grid (1,000 feet on a side) located within the sewage field. The results of these experiments were discussed in the May 1 report. The same type of experiment was done on three separate occasions during the discharge of primary effluent from the Hyperion outfall. Two grids of 25 samples each, spaced approximately 4 hours travel of the field apart, were run on each trip.

The individual counts in the grids showed the same type of distribution as was shown for the two previous Hyperion grids (May 1 report), with most of the values for any grid clustered around the geometric mean. The geometric mean of the MPN's of the individual grids are plotted on Figure 6. It can be seen that, with one exception which was low, the means fall remarkably close to the curve representing the average disappearance rate determined from the dye patch experiments. These data are further confirmation that the dye patch technique gives a representative picture of the behavior of the effluent field.

The question as to whether the fluorescein used in the dye patch experiments exerts a toxic effect on the coliforms present was previously considered. Experiments were reported (May 1

report, p. 66) that showed no dye toxicity. These experiments were run in the absence of direct sunlight and the possibility existed that a toxicity due to a photodynamic effect could occur. Consequently, toxicity of fluorescein was retested taking this factor into consideration, but no photodynamic effect could be shown. The results of one experiment are presented in Table III.

Subsurface Distribution of Coliforms

Thirty-four stations were occupied at which a series of one surface and three subsurface samples were collected and analyzed for coliforms and chlorinities. The profile constructed from one series of stations is shown in Figure 7.

As with the previous data of this nature discussed in the May 1 report, the highest subsurface counts occurred along the general lines of movement of the surface effluent field. The tongues of high coliform content extending down from the surface that were so prominent in the Orange County data did not show up as strongly in the data taken in Santa Monica Bay. There were individual high subsurface counts in areas of normal chlorinity that did suggest sedimentation as was discussed above in connection with the subsurface radioactivity measurements. In general, the evidence for sedimentation as an important factor for coliform disappearance was not as strong in the Santa Monica Bay area as in the other areas studied. This could relate to the lack of steady state discharge of unchlorinated effluent into Santa Monica Bay. Since unchlorinated sewage was only released for a few hours on the days

TABLE III

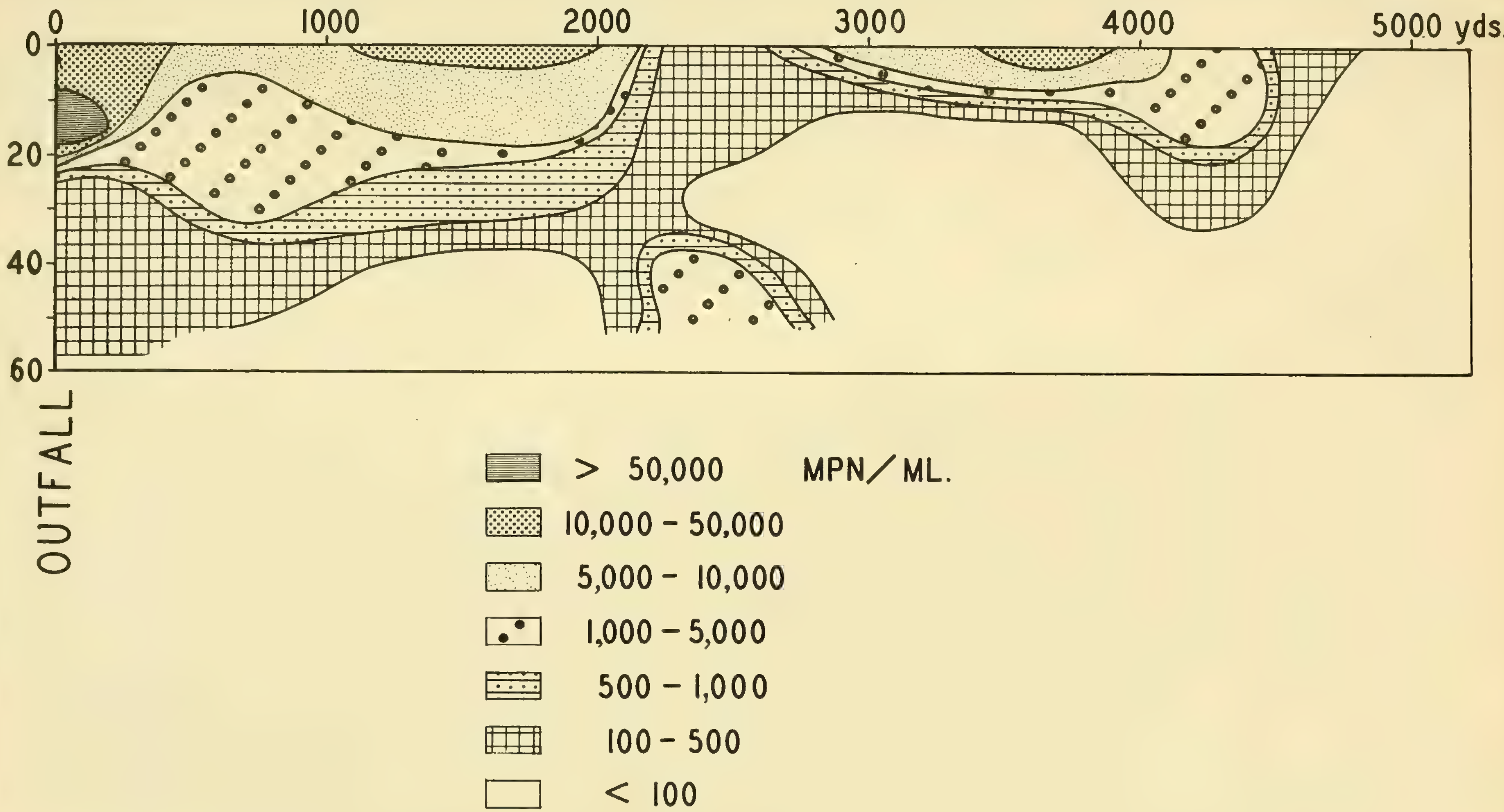
Effect of Fluorescein on Coliform Organisms

in the Presence of Direct Sunlight[1]

Time	MPN/ml with dye	MPN/ml without dye	Time	MPN/ml with dye	MPN/ml without dye
0 hour	24,000	24,000	4 hours	2,300	23
	72,000	72,000		620	6.2
2 hours	2,300	2,300	6 hours	230	0.6
	2,300	230		230	nil

1. A mixture of 5% unchlorinated primary effluent in sea water with and without 0.01% sodium fluorscein was used. A 500 ml mixture in an open beaker was exposed to sunlight for the time indicated. MPN's were determined by Standard Methods.

Figure 7. Vertical distribution of coliform bacteria at the Hyperion outfall on April 17, 1956.



HYPERION BACTERIAL PROFILE

APRIL 17, 1956

of the trips taken, most of the solids in the bay at these times were from chlorinated effluents and would be expected to contribute little or nothing to the subsurface coliform counts.

Bureau of Sanitation Results

Previous to the May 1 report, there had been an extensive discussion of the apparent discrepancies between the disappearance rates we observed using the dye patch technique, and the rates found by the Bureau of Sanitation using a different type of field procedure. This problem was discussed in the May 1 report (p. 64-71) and it was concluded that the differences in results were independent of field or laboratory technique and related only to differences in the nature of the effluents being studied. Most of our work was done on primary effluent from Orange County and most of theirs on secondary treatment effluent from Hyperion. This conclusion has been substantiated by the more recent data collected by them and us during periods of discharge of primary effluent from Hyperion. Without detailing the Bureau of Sanitation data, which are summarized in their "Summary Report, Oceanographic Investigation of Santa Monica Bay, July 1956", it is sufficient to point out that they show an average 90% reduction of coliform rate of 3.4 hours for the first nine hours after discharge as compared to our average figure of 3 hours for the first 6 to 10 hours after discharge. Further, on a single trip to the Orange County area they found a disappearance rate identical to that given in the May 1 report.

After nine hours from the time of discharge, the disappearance rate measured by the Bureau of Sanitation changes sharply and is of the order of 15 hours for a 90% disappearance of coliforms. This value is based on samples collected close inshore near the surf zone and it "is believed to reflect the boundary effects obtained in and near the surf zone where the coliforms undergo a much slower rate of reduction than in offshore waters". This same effect is reflected in the persistence of the beach counts observed on several occasions by the Bureau of Sanitation after the release of unchlorinated secondary treatment effluent for short periods of time from the Hyperion plant. The less rapid disappearance of coliforms in the surf zone was previously discussed (May 1 report) and it was pointed out that if sedimentation is an important factor in coliform disappearance, it would not be operative in the surf where turbulence would keep particulate matter in suspension. In fact, the breaking up of particles in the surf might in effect increase the apparent MPN's of the beach samples. The major significance of this effect is merely to shorten somewhat the time of travel available for effective coliform disappearance. In other words, the time of travel to the surf zone and not to the beach is the significant one. The difference between the two times, however, is small.

Summary of Water Data

The rate of disappearance of coliforms discharged from three ocean outfalls was determined by following patches of effluent tagged with fluorescein dye. The general similarity

between data obtained by this method and by three other independent methods, (using a radioactive tracer, running traverses across the sewage field, and running detailed grid patterns in the field) shows the validity of the dye patch procedure for determining the fate of coliforms in an effluent field.

Calculations based on dilutions of effluent measured by radioactivity showed that even in effluent of very recent origin from an outfall, there is a greater disappearance of coliforms than can be accounted for on the basis of dilution alone. When similar calculations are made using chlorinities as a measure of dilution, the extra disappearance over dilution is much greater, showing that fresh effluent undergoes considerable dilution by older effluent in the vicinity of an outfall.

Data obtained from subsurface samples taken below the main effluent field show that sedimentation is an important factor in the extra disappearance of coliforms. The data available were not sufficient for a precise measure of this effect and it is not certain whether die-off of coliforms and other factors are also of significance in the extra disappearance.

The disappearance rate differed with each type of effluent studied, being most rapid for the Orange County effluent and least rapid for the Whites Point effluent (although data on the Whites Point area are fragmentary). Primary effluent from Hyperion shows a more rapid rate of disappearance than secondary. The rate of disappearance may be related to the solid content of the effluents and their settling characteristics. The average value obtained for the Hyperion primary effluent, 3 hours for a 90% disappearance, is a reasonable one to employ for calculating

performance of the proposed new outfall in Santa Monica Bay, if unchlorinated primary effluent of the type studied is to be discharged.

Disappearance is less rapid once the effluent reaches the surf zone. This is explainable, if sedimentation is a major factor in removal of coliforms on the basis of the elimination of settling by the turbulence in the surf. In effect, it is only the time of travel from the outfall to the surf zone, and not to the beach, that is of importance in coliform disappearance.

CONCLUSIONS WITH RESPECT TO STATE STANDARDS

In the "Decision dated May 2, 1956, of the State Water Pollution Control Board" standards were set for the "waste discharges proposed by the City of Los Angeles in its June 13, 1955 report. . ." Of the standards set, only two refer to the permissible coliform densities and the question to be discussed in the following section is whether, in the light of the information available, they will be met. The non-bacteriological aspects of the standards will be dealt with in other sections of the final report.

In the specifications, the area around the proposed outfall is divided into three areas, each protected for different beneficial uses. Area 1 includes waters within 5,000 feet of the nearest sludge or effluent outlets; Area 3 comprises the waters between high-water line on the beach and a line 1,500 feet offshore from the high water line; and Area 2 the waters not included in Areas 1 and 3. For purposes of sampling, eight traverses were established that ran radially outward on specified

bearings from the point of origin. On each traverse there is an A station within Area 1 and B and C stations in Area 2, the locations of which are within specified distances from the point of origin of the traverse. In addition, there are a series of shoreline stations located at not greater than 10,000 feet intervals for a distance of 14 miles north and 9 miles south of the Hyperion plant. The bacteriological standards laid down specify that as determined by the B and C sampling stations "The coliform concentration, as measured by the geometric mean at the two sampling stations along each radial traverse, shall not exceed 100 per ml in any three consecutive samples or in more than 20% of any 20 consecutive samples." As determined at the shoreline sampling stations, "The coliform concentration at each sampling station shall not exceed 10 per ml in any three consecutive samples or in more than 20% of any 20 consecutive samples."

From the information available on currents in Santa Monica Bay, it can be assumed that the most rapid currents observed along any traverse will be no greater than the maximum rate observed along any other. This does not imply that the effluent will spread out equally in all directions, since the data have shown that a well-developed current system exists in the bay (see Final Current Report), but it does imply that the maximum danger of noncompliance with the standards will be along the traverses of minimum length and consequently of minimum travel time of the effluent from the outfall to the established stations. On this basis, traverses 2 and 3, which run most directly towards the beach are the most critical ones. Along these traverses, the B stations can be located between 13,000

and 17,000 feet from the outfall, and the C stations between 23,000 and 27,000 feet away. For the purposes of the further discussion it will be assumed that the B stations along these two lines are 3 statute miles (15,800 feet), the C stations 5 miles (26,400 feet), and the surf zone 5½ miles (29,000 feet) from the outfall.

In order to make any predictions, the following information must be available; (1) the rate of disappearance of coliforms, (2) the initial coliform content at the boil, and (3) the rate of travel to the surf zone (or any other point away from the boil for which prediction is desired). Each of the above factors are variable and although average values can be assigned for each, the extreme situations must be considered as well as the average situation.

The average disappearance rate of 90% reduction in 3 hours can be accepted as typical under the conditions that we studied. No individual dye patch showed a disappearance rate of greater than 4½ hours for 90% reduction, and this value is therefore used for the "worst" situation. It is possible that slower rates might occur on some occasions, but there is no way of predicting the frequency of such occurrences from our data, if they do occur at all.

Various estimates can be made of the coliform population at the boil depending on the data employed. One could accept the geometric mean of the twelve samples we collected in the boil during discharge of primary effluent, 36,000/ml, as also applying to the situation that would exist around the proposed outfall. However, since an initial dilution of at least 1/60 is

expected from the proposed outfall[1], and an average dilution of only about 1/25 (based on radioactivity measurements) occurs around the existing outfall, the above value should be corrected by a factor of 25/60 giving an average value of about 15,000/ml for the proposed outfall. One could also use the MPN's of the primary treatment effluent per se and correct these for the expected initial dilution. Plant data, summarized by the Hyperion Engineers, give the following values for the coliform content of primary effluent: 259,000/ml, as the geometric mean of 257 grab samples taken over a year's period at the same clock time for each sample; 561,000/ml as the geometric mean of 24 samples taken over a 24 hour period; 389,000/ml as the geometric mean of a similar series taken over a different 24 hour period. Applying the factor of 1/60 as the minimum expected dilution, the above values would yield coliform densities at the boil of 4,300, 9,400, and 6,500/ml, respectively. Using the boil counts obtained on the tracer cruise, calculating back to the initial count of the effluent (see Table I) on the basis of radioactivity, and again assuming a minimum dilution of 1/60 at the boil for the proposed outfall, a boil count of 12,000/ml is obtained. The highest and lowest estimates from these data differ by a factor of four which represents a little less than 2 hours disappearance time at the rate of 3 hours for 90% disappearance. The highest value, 15,000/ml at the boil, is arbitrarily accepted as the average

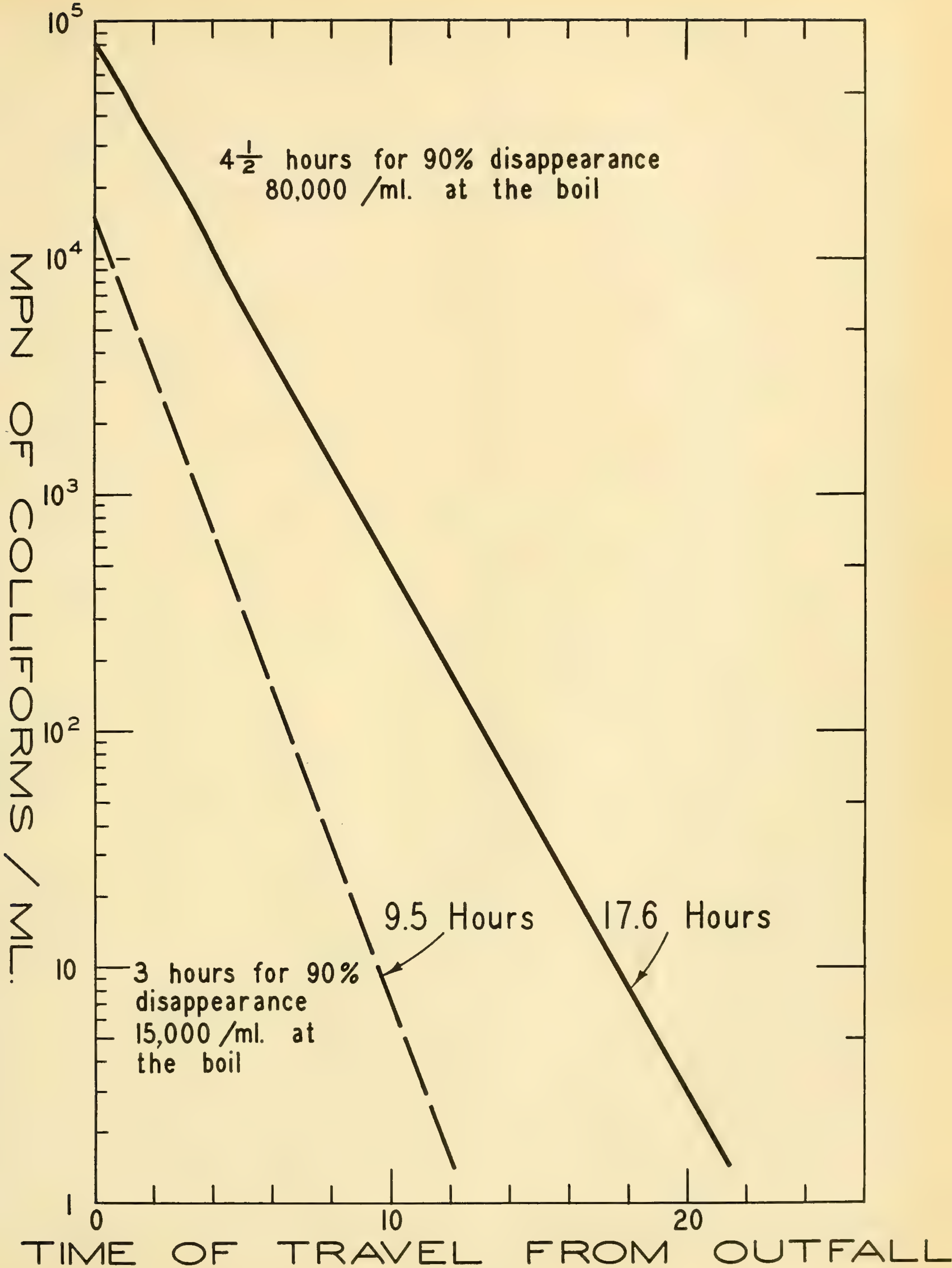
1. This is the figure cited by the Hyperion Engineers as resulting from Dr. Brooks' studies on the design of the proposed outfall. A larger or smaller value would change the calculations proportionately.

count to expect, since this is the safest assumption that can be made.

The count at the boil could be higher than the figure chosen if either the estimate of initial dilution is too high, or if the coliform content of the primary effluent is higher than the figures cited. Although reasonable estimates of the "worst" situation are difficult to arrive at, one would not expect any appreciable volume of a primary effluent to have a coliform content of greater than 2,000,000/ml, nor would one expect the proposed outfall to give a lower initial dilution than the present outfall, or 1/25. Using these two values for the worst situation that might exist at any time at the proposed outfall, a value of 80,000/ml is obtained for the boil count.

Using the average and worst values arrived at, one can calculate the expected coliform count at any time of travel from the outfall. In Figure 8 is a graphic presentation of these calculations. From these curves it can be seen that movement of the water to the surf zone in less than $9\frac{1}{2}$ hours is required before the State Standards for the beach would be exceeded under averaged conditions of initial coliform population and disappearance rate. The comparable figure for the worst situation envisioned is $17\frac{1}{2}$ hours. These times correspond to critical current velocities directed towards the beach of 0.58 and 0.31 statute miles per hour, respectively. At these velocities the calculated geometric mean of the B and C station counts are 72 and 100, respectively. In other words, if the beach stations meet State specifications, then the B and C stations will also comply.

Figure 8. The MPN of coliforms versus time of travel from the outfall.



MPN OF COLLIFORMS / ML.
TIME OF TRAVEL FROM OUTFALL
$4\frac{1}{2}$ hours for 90% disappearance
80,000 /ml. at the boil
3 hours for 90% disappearance
15,000 /ml. at the boil
9.5 Hours
17.6 Hours
10^5
10^4
10^3
10^2
10
1
0
10
20

The current data obtained during the bay survey is dealt with in an accompanying report and will not be considered in detail here. However, an inspection of the drift card returns show that the great majority of the cards released at the sites of the proposed sludge and effluent lines required considerably longer than 24 hours to reach the beach, if they were carried ashore at all. Actually, only two required less than 24 hours, the times being 21 and 18 hours, respectively. Even this rate of movement would not result in beach pollution under the worst set of conditions assumed. Therefore, on the basis of measured currents around the proposed outfall sites, one must conclude that there is an ample margin of safety as for meeting the coliform requirements set down.

It must be pointed out that velocities of greater than the critical ones cited above were found in the bay. Individual drift cards released on 2 of the 13 trips had velocities exceeding 0.58 miles per hour, and on 4 of the 13 trips exceeding 0.31 miles per hour, with one cruise (Aug. 20 and 21) not included. For the most part, the high velocities were from cards released in the inshore stations, particularly those towards the south end of the bay. In some of these instances the cards did not move directly to the beach, so even though the velocities were high the actual time of travel in the water would have been sufficient to reduce the coliform population below the specified maximum. However, many cards of high velocity traveled directly towards shore.

If sustained currents towards the beach of greater than 0.58 miles per hour were observed more than 20% of the time,

non-compliance with State Standards would certainly be expected. If, however, sustained currents of greater than 0.31 miles per hour towards the beach were found 20% of the time, the possibility of compliance would still be good since extreme conditions were postulated to arrive at this "worst" value. From the current data available for the proposed outfall stations, one can only say that neither of these conditions seem to prevail, taking the year's measurement as a whole and, therefore, general compliance with State Standards would be predicted. However, if conditions at the inshore stations are applied to the proposed outfall positions, compliance is dubious.

One further point needs discussion, and that is the specification that no three consecutive samples at any single beach station should exceed a count of 10/ml. If the temporary existence of a high velocity current brings a slug of effluent into the surf zone in less than the critical time, then the slower rate of disappearance of coliforms in the surf could result in excessive counts for periods much longer than the existence of the current. For example, 24 hours of a sustained current of greater than 0.58 miles per hour toward the beach could give high beach counts for as much as 48 hours thereafter. Chlorination of the effluent being discharged subsequent to the initial 24 hours would not be effective in remedying the situation. Since currents of this velocity have been measured on occasion, one must anticipate occasional difficulties in complying with the above standard, even though the frequency of such occurrences is low.

In final summary then, the data indicate that an ample margin of safety appears to exist for complying with State Standards on an overall basis. They do not, however, rule out the possibility of restricted periods of non-compliance.

COLIFORMS IN THE BOTTOM SEDIMENTS

Introduction

Previous to the May 1 report, two series of bottom samples were collected in Santa Monica Bay and analyzed for their coliform population. Less intensive sampling was also conducted in the vicinity of the Whites Point outfall and around the Orange County outfall. In all three areas, coliforms were found for considerable distances around the outfalls. The numbers observed were variable and samples taken at approximately the same location near the Orange County outfall gave widely different coliform counts. It was believed that part of the variation was due to difficulties in the sampling technique, in particular the difficulty of capturing all of the uppermost sediment layer where the coliforms should be most abundant, using either the snappers or the coring instrument (May 1 report, p. 53-57). As a consequence, a new sampling apparatus was developed and the coliform populations in the sediments were reinvestigated.

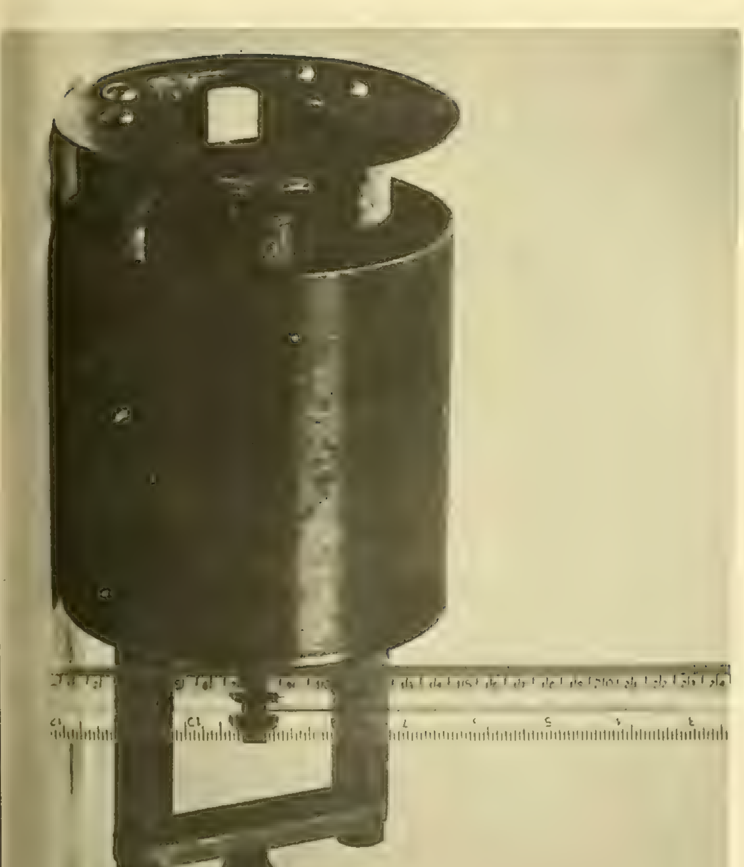
Sampling Methods

Samples were collected by two procedures, either employing divers or else using a specially-designed bottom sampling apparatus. The divers were used for the inshore samples that

could not be reached by ship. They were provided with glass tubes open on both ends, about 2 cm in diameter and 6 cm long, having a cross-sectional area of 2.5 cm^2. These were filled with sterile water and closed with caps that fitted over the ends of the tubes. To take a sample, the diver removed the caps, pushed the tube into the bottom, and then replaced the caps. Although a somewhat variable depth of the sediment column is taken by this procedure, the entire surface layer is captured, and this layer is the significant portion. When the capped tubes were returned to the divers' launch, their entire contents were transferred to sterile water blanks of proper volume to give an initial dilution of 2.5 cm^2/100 ml of surface area of sediment. From this initial dilution, further dilutions of ten fold increments were prepared and coliform contents determined by Standard Methods. The counts were calculated on the basis of MPN's/cm^2 surface area of sediment.

The sampling apparatus used from the VELERO IV is shown in Figure 9. A vial of 2.5 cm^2 cross-sectional area, filled with sterile water, is inserted into the vial holder while the sampler is in an inverted position. The apparatus is then cocked, bringing a metal plate across the mouth of the vial, which closes it. The sampler is turned upright, maintaining a tension on the cable during this operation, and then lowered to the bottom. When the foot of the sampler hits the sediment, the plate pulls back allowing the vial to penetrate a cm or two into the bottom, depending on the type of sediment. As the cable is wound in to retrieve the sample, the plate closes, sealing the sample in the vial. When the sampler is brought

Figure 9. Bottom sediment sampler for obtaining samples for coliform determination. Designed by Dr. K. O. Emery, and constructed by Mr. Alexander Campbell, Chief Engineer of the VELERO IV.



on deck, it is inverted, the vial is removed, and the vial contents are introduced into a sterile dilution bottle. The procedure from this point on is the same as with the diver samples.

Results

Using these techniques, 100 samples were collected in the vicinity of the Orange County outfall on a series of parallel lines from about $1\frac{1}{2}$ miles down coast to 3 miles upcoast from the outfall. On each line, one sample was taken at the water line, one in the surf, and the remainder spaced out to three miles offshore. Most of the samples to a depth of 60 feet were taken by the divers, the deeper ones being collected from the VELERO IV. On several stations samples were collected by both techniques and these showed similar coliform counts. Using the same procedures, 110 samples were taken in Santa Monica Bay in a similar pattern. After the bacteriological aspects of the bay project were completed, a similar series of samples were taken in the vicinity of Whites Point using funds provided by the Los Angeles County Sanitation Districts for the trip. The data from this trip is included in this report with their permission.

Table IV summarizes certain aspects of the data obtained and Figures 10, 11, and 12 map the extent and intensity of the bottom coliform fields found in the three areas. It can be seen that the coliform fields around the Orange County and Whites Poing outfalls, where unchlorinated effluent is constantly discharged, occupy an extensive area and contain large numbers of

TABLE IV

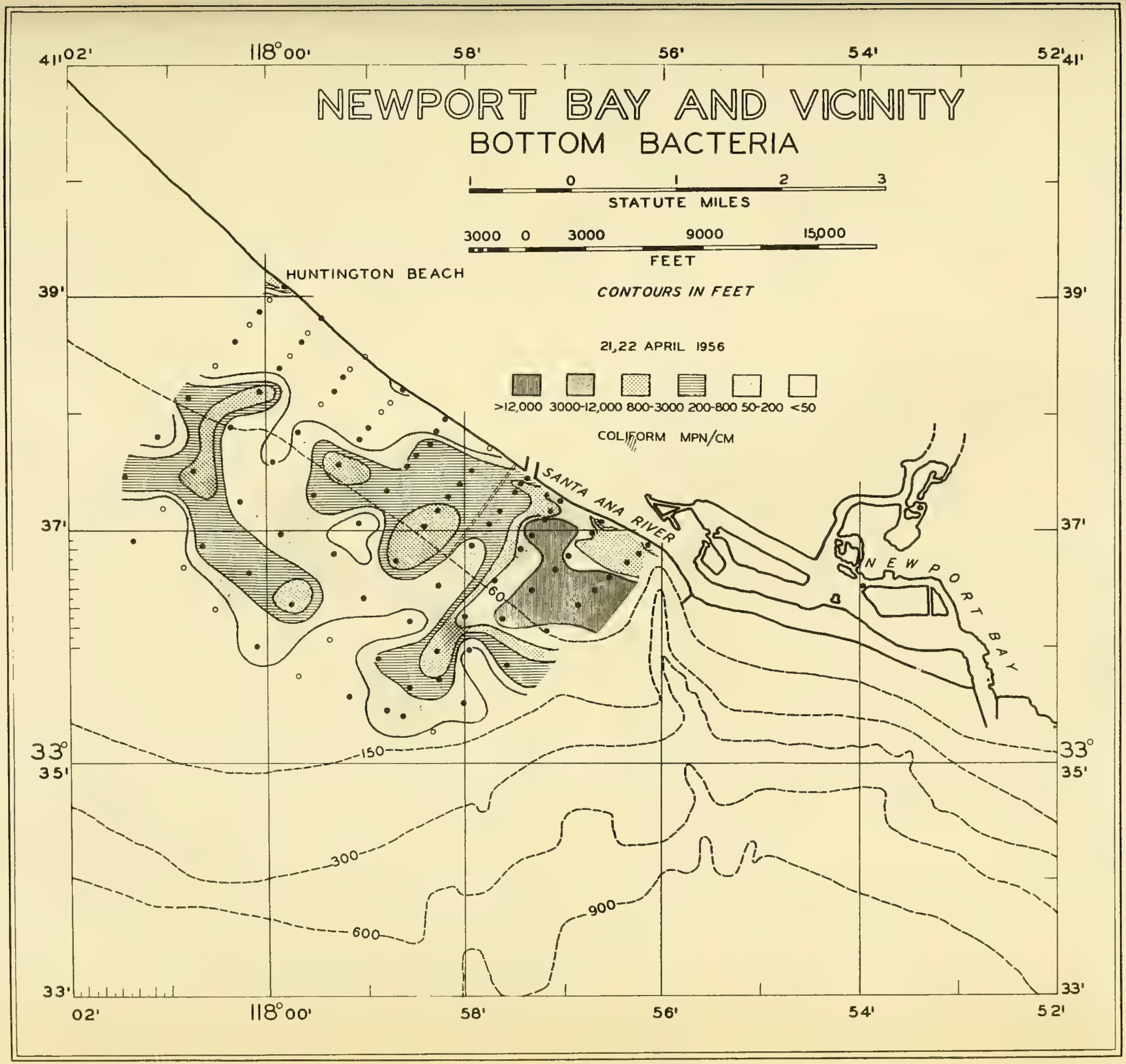
Coliform Bacteria in Bottom Sediments

Location	Number of samples	Number positive	Range of MPN/cm^2
Orange County	100	83	nil to 25,000
Santa Monica Bay	109	9	nil to 250
Whites Point	106	72	nil to 92,000

Figure 10. Bottom coliform field in the vicinity of the Whites Point sewer outfall.

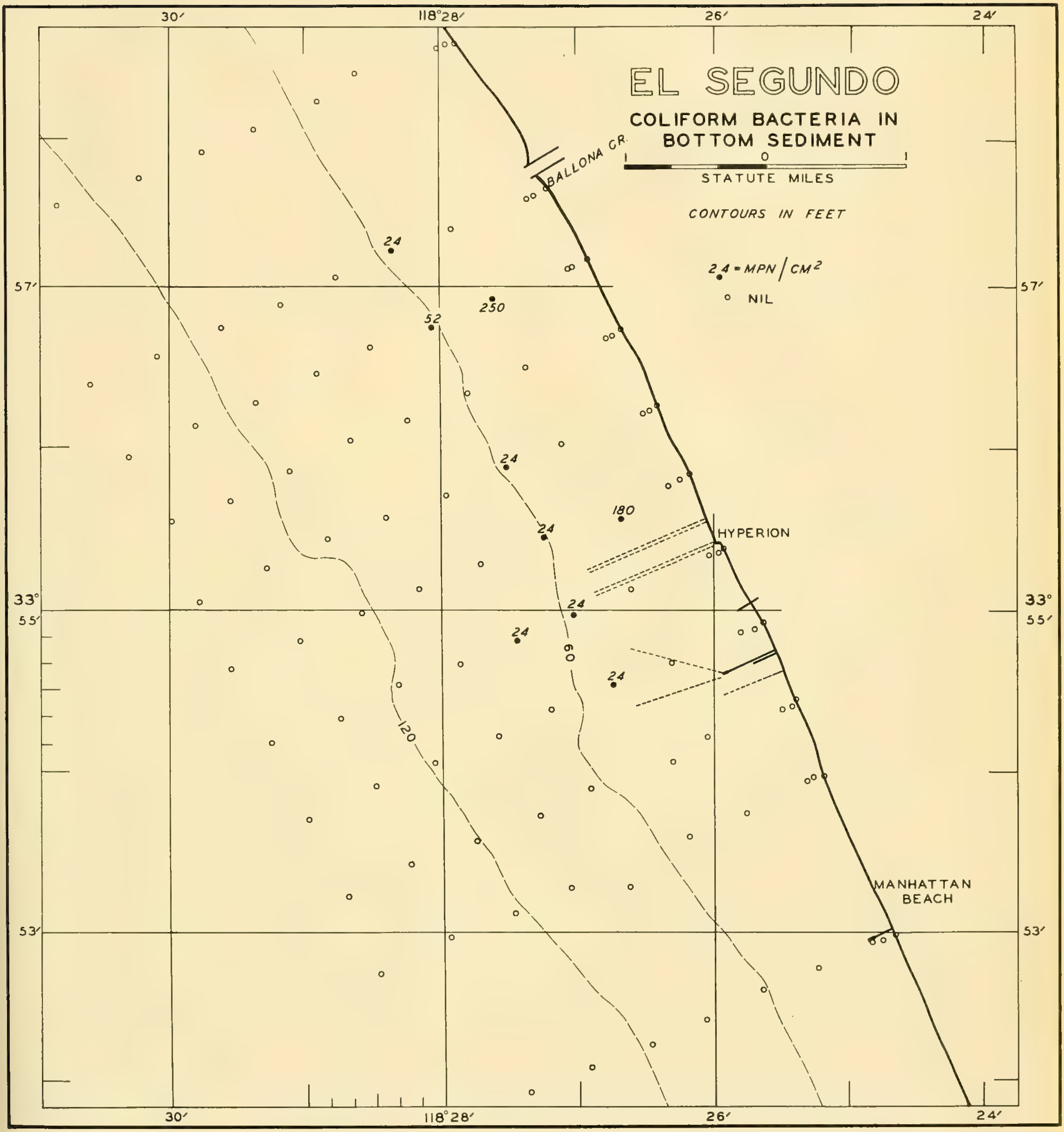
25'
118°20'
15'
45°
45'
33° 40'
PALOS VERDES HILLS
300 FEET
> 10.000
1.000-10.000
100-1000
1-100
NIL
MPN COLIFORMS / CM²
0
1000
6000
YARDS

Figure 11. Bottom coliform field in the vicinity of the Orange County sewer outfall.



NEWPORT BAY AND VICINITY
BOTTOM BACTERIA
1 0 1 2 3
STATUTE MILES
3000 0 3000 9000 15,000
FEET
CONTOURS IN FEET
21,22 APRIL 1956
>12,000 3000-12,000 800-3000 200-800 50-200 <50
COLIFORM MPN/CM
HUNTINGTON BEACH
SANTA ANA RIVER
NEWPORT BAY
60
150
300
600
900
118°00'
58'
56'
54'
52'
02'
41'
39'
37'
33°
35'
33'

Figure 12. Bottom coliform field in the vicinity of the Hyperion sewer outfall.


EL SEGUNDO
COLIFORM BACTERIA IN
BOTTOM SEDIMENT
1
0
1
STATUTE MILES
CONTOURS IN FEET
24 = MPN / CM²
NIL
BALLONA CR.
HYPERION
MANHATTAN BEACH
30′
118°28′
26′
24′
57′
33°
55′
53′
24
250
52
24
180
24
24
24
24
60
120

coliforms. In the vicinity of the Orange County outfall the highest counts were observed down coast from the outfall and extended to the beach. One sample, taken at the water line about 3,000 feet down coast from the outfall position, had a MPN of over $5{,}000/cm^2$. It should be mentioned that this sample, as well as other high count samples, appeared to consist of clean sand with no visible evidence of sludge deposits. In qualitative terms, the distribution of coliforms in the sediments appears to follow the movement of the surface effluent field on the days of our trips to Orange County.

The distribution of coliforms in the sediments around Whites Point differed somewhat from that observed at Orange County although an equally large, if not more extensive, field existed. The highest concentration of coliforms followed a line travelling up coast from the outfall parallel to the shore and rounding Point Vicente, and down coast and seaward past Point Fermin. The data also showed coliforms off the entrance to the harbor which could have come from the outfall discharging inside of the breakwater. Contrary to what was found around Orange County, however, the waterline samples, with two exceptions for the stations directly behind the outfall, were negative. The distribution of coliforms in this area generally coincided with the distribution of three other markers of high organic matter content undoubtedly of outfall origin; the distribution of black sediments; the distribution of H_2S in the sediments; and the distribution of _Chaetopterus variopedatus_ (Figure 13).

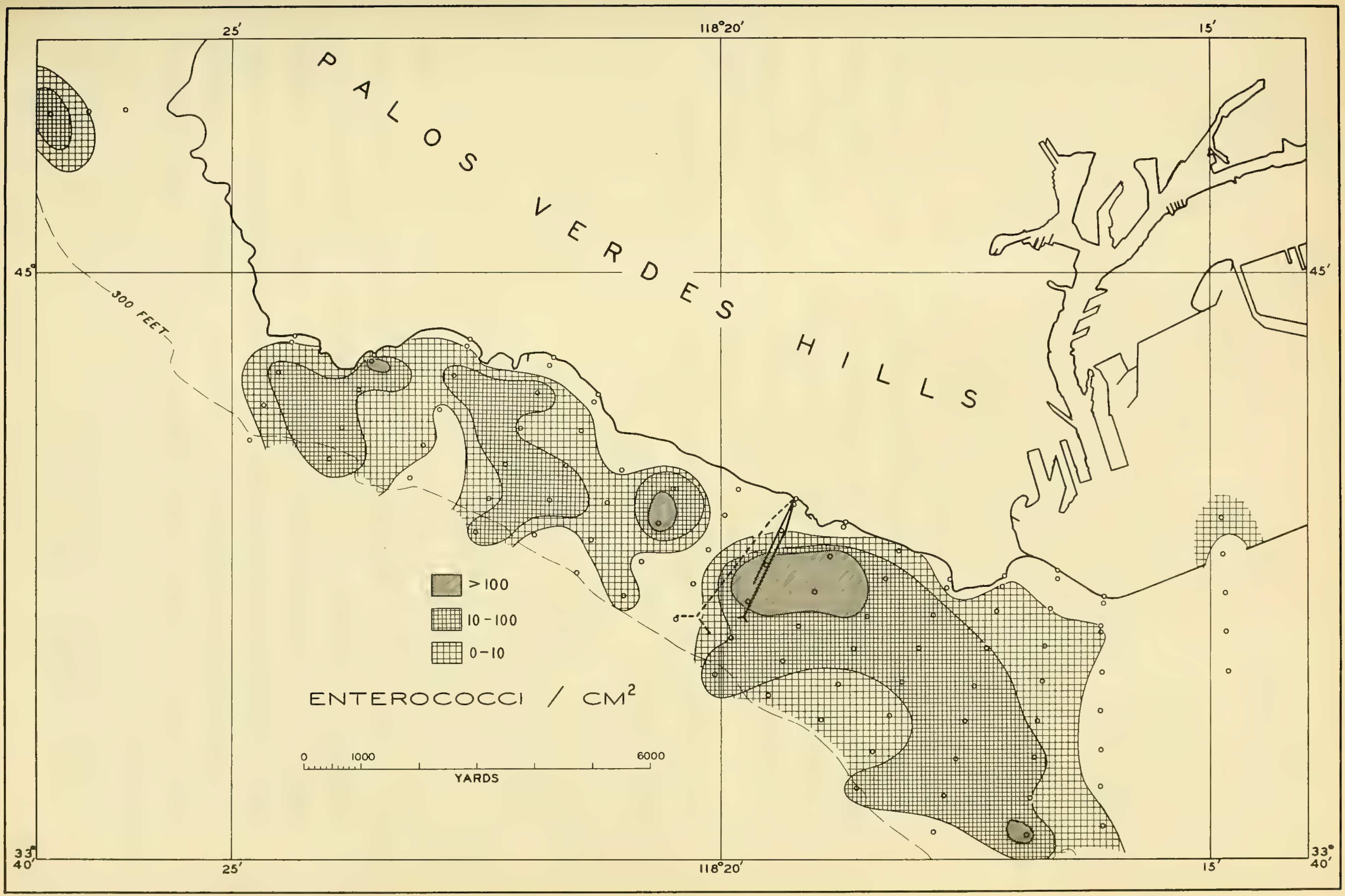
Figure 13. The distribution of black sediment, hydrogen sulfide, and *Chaetopterus variopedatus* in the vicinity of the Whites Point sewer outfall.

PALOS VERDES HILLS
SECHI READINGS IN FEET
B BLACK SEDIMENT
S HYDROGEN SULFIDE
C CHAETOPTERUS VARIOPEDATUS
0 1000 6000
YARDS
300 FEET
15
5
25
25′
118°20′
15′
45°
45′
33° 40′

In addition to coliform determinations, samples were used to enumerate enterococci by the molecular filter technique (these determinations were made by personnel from the laboratory of the Los Angeles County Sanitation Districts, who were present aboard the VELERO IV). The data obtained is contoured in the same fashion as the coliform data (Fig. 14). A comparison of the two sets of contours shows that there is a reasonable similarity between them down coast from the outfall where an area of relatively high counts of both types of organisms extend past Point Fermin. In the upcoast direction, correlation is not as good. A series of apparently isolated highs of enterococci were found whose course is along the continuous tongue of high coliforms found in this area. Whereas the coliform contours strongly suggest the outfall as the source of all the coliforms in the area (excluding perhaps the high pocket just offshore from the Oceanarium and the pocket off the entrance to the harbor), the discontinuous nature of the enterococci distribution might suggest multiple sources of these organisms.

When the coliform count is plotted against the enterococci count, the most apparent relation is that the majority of the samples (excluding those where both counts were nil) have coliform counts ten or more times the enterococci counts. There is no constant ratio between the numbers of the two types of organisms, nor is there any obvious trend of either increasing or decreasing ratio with distance from the outfall. It has been suggested that a comparison of coliform and enterococci counts might provide a basis for distinguishing between fecal and nonfecal coliforms or between coliforms of recent or older origin.

Figure 14. The distribution of enterococci in the vicinity of the Whites Point sewer outfall.



PALOS VERDES HILLS
300 FEET
>100
10-100
0-10
ENTEROCOCCI / CM²
0
1000
6000
YARDS
25′
118°20′
15′
45′
33° 40′

In contrast to what was found in the other two locations, only a few of the sediment samples collected in Santa Monica Bay showed the presence of coliforms, and in these samples the numbers were low. This is what one would expect considering that essentially all the effluent discharged in the area is chlorinated. However, a comparison of Figure 11 with Figure 15 of the May 1 report shows that in areas where positive samples had been obtained previously, negative ones were found on the last survey. The only reasonable explanation for this situation is that the coliform field in this area is either transitory timewise because of only sporadic discharge of large coliform populations, or else is very unevenly distributed.

In examining the samples taken from the Santa Monica Bay area on the last survey trip, it was found that a large number of positive lactose broth tubes failed to confirm on EMB agar. An effort was made to determine the cause of these "false positive" tubes. Although the work could not be completed because of lack of time, it was found that at least part of these false positives were due to lactose fermenting aerobic and anaerobic spore formers. More important, it was found that a high per cent of the positive lactose tubes that did not confirm on EMB gave positive results when transferred to brilliant green bile broth. Further examination showed that these positive brilliant green tubes did not contain coliforms. Although these findings do not bear directly on the question at hand, they certainly indicate that the use of brilliant green bile medium for confirmation test should not be considered in any project dealing with marine sediments.

Discussion

The presence of extensive coliform fields around the two outfalls where unchlorinated effluent is now being discharged makes it appear certain that a similar field will be built up around the proposed new effluent line in Santa Monica Bay. Considering current directions and the volume of solids to be discharged, there is every reason to believe that the coliform field will eventually reach the beach zone as it apparently has around the Orange County outfall. The expected occurrence of such a field raises several important problems that will be discussed in turn.

Since there are at present no specifications relating directly to the coliform content of the sediments per se, the question of compliance or non-compliance with State Standards arises only indirectly. In attempting to explain the occurrence of high beach counts in the vicinity of the Orange County outfall in spite of the rapid disappearance rate for coliforms measured in that area, one possibility proposed was that the high counts might be related to the disturbance of the bottom coliform field during periods of strong wave action (see May 1 report). This proposal was put forth before the full extent of the coliform field in the sediments around this outfall was known and the subsequent finding of relatively high counts even at the water line certainly made the idea more plausible. If one accepts the conclusion that a similar field will be built up around the proposed Hyperion outfall, then the possibility that bottom coliforms might contribute to the beach counts must be considered for the Santa Monica Bay area also. Actually there

is no direct evidence available in favor of this hypothesis, and at least one instance is known where this situation might have been expected to occur and did not. During the past few months there were at least two occurrences of high counts all along the Orange County beach during periods when wave action was not intense, and one occurrence of a high surf from the south for two successive days without any surge in beach counts. All one can conclude from these limited experiences is that although the possibility exists, the likelihood is uncertain.

Although at the present there are no specifications in regards to the coliform content of the sediments, it could be argued that some of the beneficial uses protected in Area 2 and Area 3 might be impaired by their presence on the bottom. This would be especially true if there were indications that the presence of coliforms in the sediments could have a public health significance. It can be argued that if coliforms are present, then pathogens might equally well be present, and could be carried into the water under proper conditions of turbulence. The only countering arguments would be that coliforms survive longer in the sediments than pathogens, and the latter have not been detected in marine sediments. Unfortunately, the arguments either way are without substantial experimental foundation at the moment. Both the water and sediment data indicate the possibility of a much longer persistence of coliforms in the marine environment than most investigators previously suspected. However, the question as to exactly how long they can survive or whether they can even multiply (especially in the mud) remains unanswered. As far as pathogens are concerned, the author knows

of only one attempt to recover them from the sediments off our coasts, and that was the work cited in the May 1 report in which examination of 70 sediment samples from Santa Monica Bay for enteric pathogens proved negative. Certainly, considering the importance of the question this is not an adequate sampling, since from what is now known one would choose either the Whites Point or the Orange County areas for such a survey.

It is not the intention of the author to attempt to anticipate any action on the part of the Water Pollution Control Board which might result in the establishment of coliform standards for the sediments. In terminating this discussion, however, I would like to express two opinions; first, there is at the moment insufficient evidence pro or con to decide whether such standards are necessary; second, that every effort should be made to obtain the information necessary for a considered decision.

Summary

It has been shown that an extensive coliform field exists in the sediments around the Orange County and Whites Point outfalls where unchlorinated effluent is being discharged constantly. Although coliforms have been found around the present Hyperion outfall, it is believed that their occurrence is either transitory or else that they are unevenly distributed. It is predicted that a similar coliform field would build up around the proposed new outfall and ultimately extend to the shore.

The possibility that coliforms in the inshore sediments could contribute to the beach counts in the water during periods of

heavy wave action exists. However, from the available evidence this occurrence appears remote.

The question as to whether the presence of coliforms in the sediments has a public health significance has been briefly discussed. It is the author's opinion that our current information is too fragmentary to allow a reasonable answer to this question.

THE FATE OF COLIFORM BACTERIA

IN THE VICINITY OF THE

ORANGE COUNTY, LOS ANGELES COUNTY,

AND HYPERION SEWER OUTFALLS

An Interim Report

Department of Geology

University of Southern California

May 1, 1956

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An Interim Report

INTRODUCTION

During the early stages of an oceanographic survey of Santa Monica Bay it was noted that ocean current velocities over the central part of the continental shelf were low and variable. Velocities rarely exceeded 0.35 knot and the average was 0.2 knot. The direction of flow was also quite variable for periods of time greater than 2 hours, so that the net water motion was approximately 0.1 knot. The dominant direction of flow extending over periods of several days was generally shoreward with digressions due to winds, tides, and local man-made phenomena.

The slow transport of water over the central part of the shelf required modification of the philosophy of sewage discharge into the bay. It had been considered that if the outlet were placed five miles from the nearest shore and if mechanical diffusion of the effluent would produce an initial dilution of 1/1000, then the initial bacterial population would be low enough to allow health standards to be met if sewage reached the surf zone. However, because of the low volumes of sea water passing the proposed discharge site, an initial dilution greater than 1/100 should seldom occur regardless of the efficiency of mechanical diffusion.

It was necessary, therefore, to determine with a reasonable degree of accuracy the rate at which coliform bacteria disappeared from sea water after their introduction with the

unchlorinated sewage. It was recognized that the disappearance would be due to several factors and that dilution, mortality, and sedimentation were probably the most important. Dilution could be measured to roughly one part in 400 by chlorinity determinations, but experiments were not designed to distinguish between other causes of disappearance.

Twelve cruises were conducted between September 1955 and February 1956. Of the cruises, ten were to determine the distribution of coliforms in time and space and two were to reinvestigate the bottom coliform field in Santa Monica Bay.

The sea around the Orange County outfall was chosen as the principal area of investigation because the discharge was primary unchlorinated effluent and the oceanography was similar to that in the shallow areas of Santa Monica Bay. The waters surrounding the Los Angeles County outfall at Whites Point were investigated to check results obtained at Orange County and to note the distribution of coliforms as affected by a deeper point of discharge and better mechanical diffusion. In both areas, the occurrence of bottom coliforms was determined, but the extent of the fields was not investigated.

Although the volume of sewage discharging from each of the outfalls differs, it was believed that the processes relating to the disappearance of the bacteria from the waters would be the same. The results have shown this to be more or less true. However, the rates of disappearance were different around the three outfalls and from the data obtained during a cooperative cruise with the Los Angeles Sanitation District at the Hyperion outfall, it seems possible that the physical and chemical dif-

ferences between the effluents might be a considerable factor of importance.

Two parameters that would probably affect coliform disappearance are analyzed by the sanitation districts with enough frequency to give satisfactory averages. These are suspended solids and chlorinity. The averages for the three outfalls are as follows:

	Orange County	Whites Point	Hyperion
Average daily flow - mgd	25	177	250
Average Suspended solids ppm	115	240	221
Average chlorinity 0/00	2.5	0.70	0.25

BOTTOM SEDIMENTS IN THE OUTFALL AREAS

Whites Point

The sea floor of the continental shelf off Whites Point is an area of accumulation of land-derived sandy silts. The color of the sediment ranges from dark olive-green to black, the latter color being the result of a high sludge content in the sediment. Bottom material with a high sludge content releases a strong odor of hydrogen sulfide, an indication of oxygen deficiency (Table 1). All material in the sampling area, which covered 1.5 square miles around the outfall, contained varying quantities of the particulate sewage debris, but there is no apparent pattern that would be indicative of different rates of sludge sedimentation.

TABLE 1

SEDIMENTS IN THE AREA OF THE WHITES POINT SEWER OUTFALL

Sample Number	Classification	Per Cent Sand	Per Cent Silt	Per Cent Clay	Per Cent Calcium Carbonate	Median Diameter	Sorting Coefficient	Color (wet)
3551	Sandy silt	41.1	49.4	9.5	13.1	0.052	2.22	Black to Dk. oliver-green
3552	Silty sand	47.5	45.4	7.1		0.060	1.90	Black to Dk. olive-green
3553	Sandy silt	35.1	48.4	16.5	19.0	0.043	2.29	Black
3554	Sandy silt	39.0	54.7	6.3	11.9	0.053	1.76	Dark olive-green to black
3555	Sandy silt	43.8	44.8	11.4		0.056	2.25	Dark olive-green to black
3556	Sandy silt	41.2	49.4	9.4	10.2	0.054	1.84	Dark olive-green to black
3557	Sandy silt	41.8	54.6	3.6		0.057	1.82	Dark olive-green to black
3558	Sandy silt	38.9	49.1	12.0	7.9	0.050	2.07	Dark olive-green to black
3559	Sandy silt	27.4	57.5	15.1	9.4	0.036	3.19	Dark olive-green to black
3560	Sandy silt	40.9	50.4	8.7	8.4	0.051	2.40	Dark olive-green to black
3619	Sandy silt	43.5	45.0	11.5	12.2	0.048	2.48	Dark olive-green

(Continued)

TABLE 1 (Continued)

Sample Number	Classification	Per Cent Sand	Per Cent Silt	Per Cent Clay	Per Cent Calcium Carbonate	Median Diameter	Sorting Coefficient	Color (wet)
3620	Sandy silt	22.1	65.1	12.8	4.9	0.035	2.49	Dark olive-green to black
3621	Sandy silt	37.2	51.0	11.8	9.6	0.049	1.98	Dark olive-green
3622	Sandy silt	20.1	75.6	4.3	9.7	0.029	2.36	Dark olive-green to black
3623	Silty sand	53.1	41.2	5.7	12.1	0.068	2.11	Dark olive-green
3625	Sandy silt	43.7	45.6	10.7	12.0	0.055	1.87	Dark olive-green to black
3626	Sandy silt	29.9	64.4	5.7	9.6	0.042	1.87	Dark olive-green to black
3627	Silty sand	48.5	40.0	11.5	8.8	0.060	1.87	Black to dark olive-green
3628	Sandy silt	30.4	55.4	14.2	11.6	0.037	2.80	Dark olive-green to black
3651	Sandy silt	38.6	48.4	13.0	11.2	0.046	2.11	Dark olive-green to black
3652	Silty sand	49.8	39.6	10.6		0.061	2.11	Black to dark olive-green
3653	Silty sand	63.4	29.3	7.3	13.3	0.810	2.74	Black to dark olive-green

There is little lateral variation in the type of sediment in this area, for the range in median diameters of all samples was 0.029 mm to 0.081 mm, the average being 0.051 mm. Grains of silt size are the most abundant, representing 50% of each sample. Sand size material constitutes 40% and clay size fragments 10% of the bottom material. The sediment is well sorted having an average Trask sorting coefficient of 2.21. The abundant quartz and feldspar grains in the sand fraction are angular. The range in the calcium carbonate content, derived from shells and shell fragments, is low with an average of 11%.

From the data and an examination of the bottom sediments it is believed that this is an area of reasonably rapid deposition of detrital material, probably derived mainly from the adjacent sea cliffs. The inclusion of sludge in the deposits results in a dark color, a deficiency of oxygen in some of the sediments, and a likely overall reduction in the average grain size due to the fine nature of the particulate sludge debris.

Orange County

The sea floor in the vicinity of the Orange County ocean outfall is an area where sand accumulates nearshore and grades to silty sand offshore. The color of the sediment ranges from a light gray to almost black, and nearly all samples contain small blobs or streaks of sludge. The darker sediments, indicating a high sludge content, are generally farther from shore, although the bottom material south of the outfall also has fairly high quantities of this organic debris. Even though material of sewage origin is obvious in the sediments, no samples gave more

than a slight hint of hydrogen sulfide odor; thus, the sediments are not deficient in oxygen.

The bottom sediments here are much better sorted and coarser grained than those near Whites Point (Table 2). The range in median diameters is from 0.072 mm to 0.187 mm, with the higher medians occurring in the material closer to shore. The sorting coefficient averages 1.26, indicating the sediment to be very well sorted, approaching that expected in sands of the nearby beaches. This is not unusual, of course, because the source of the offshore sands is the adjacent beach, with a minor amount of material being contributed by the Santa Ana River during storms.

The sands are relatively clean, with silt and clay grains constituting only 25% of the average sample. Grains in the sand fraction are angular and are comprised almost solely of quartz and feldspar, with quartz making up more than 50% of each sample. The calcium carbonate content, derived from shells and shell fragments, is especially low, averaging only 3% of the sediment.

Sedimentation of beach-derived material is fairly rapid in this area and overshadows the addition of other materials, including sludge, by a great percentage. The only noticeable effect of the sewage discharge is a discoloration of the bottom material in an offshore and southerly direction.

Santa Monica Bay

Although a general description of the bottom sediments in Santa Monica Bay was given in the First Quarterly Progress Report, it is well to review the sediment distribution to relate it with the discussion of coliform bacteria in the bottom sediments in this report.

TABLE 2

SEDIMENTS IN THE AREA OF THE NEWPORT BEACH SEWER OUTFALL

Sample Number	Classification	Per Cent Sand	Per Cent Silt	Per Cent Clay	Per Cent Calcium Carbonate	Median Diameter	Sorting Coefficient	Color (wet)
3561	Very fine sand	100				0.120	1.26	Gray
3563	Very fine sand	100				0.109	1.30	Gray
3564	Very fine sand	100			2.0	0.102	1.39	Gray
3565	Very fine sand	100			2.6	0.100	1.15	Gray
3566	Silty sand	74.1	23.1	2.8		0.077	1.27	Gray
3567	Fine sand	100			1.5	0.128	1.23	Gray
3568	Fine sand	100			2.1	0.138	1.25	Gray
3569	Silty sand	71.6	22.2	6.2	5.5	0.076	1.30	Dark gray
3632	Fine sand	100				0.187	1.21	Dark gray
3633	Very fine sand	100				0.105	1.27	Gray
3634	Fine sand	100			2.5	0.125	1.48	Dark gray
3635	Fine sand	100				0.140	1.33	Gray
3636	Fine sand	100				0.128	1.29	Dark gray
3638	Fine sand	100			1.4	0.160	1.23	Dark gray
3639	Fine sand	100			2.0	0.155	1.28	Gray
3640	Fine sand	100			1.6	0.160	1.28	Dark gray

(Continued)

TABLE 2 (Continued)

Sample Number	Classification	Per Cent Sand	Per Cent Silt	Per Cent Clay	Per Cent Calcium Carbonate	Median Diameter	Sorting Coefficient	Color (wet)
3666	Fine sand	100			1.7	0.161	1.31	Dark gray
3401	Fine sand	92.9	4.8	2.3		0.176	1.24	Dark gray
3402	Very fine sand	94.8	2.8	2.4		0.107	1.21	Dark gray
3402	Very fine sand	90.1	7.8	2.1		0.100	1.25	Dark gray
3404	Very fine sand	98.0	0.1	1.9		0.120	1.30	Dark gray
3405	Very fine sand	89.5	7.3	3.2		0.078	1.19	Dark gray
3406	Very fine sand	89.5	7.3	3.2	3.5	0.078	1.19	Dark gray
3407	Very fine sand	83.1	12.7	4.2		0.076	1.19	Dark gray
3408	Very fine sand	85.4	10.2	4.4	4.2	0.080	1.20	Dark gray
3409	Silty sand	70.8	23.1	6.1		0.072	1.25	Dark gray

The floor of Santa Monica Bay is composed of six bottom material types: rock, gravel, sand, silty sand, sandy silt, and silt. The extent of rock outcrops was determined with a rock dredge which in many lowerings broke off fragments of rock. Pieces of siliceous and non siliceous shale were most frequently recovered, but one large fragment of schist representing a portion of a breccia was also recovered. Bathymetric data indicate that the rock outcrops rise as irregular and scattered mounds. The gravel surrounding the outcrops consists chiefly of coarse sand, well-rounded granules, and pebbles of granite, shale, chert, quartzite, schist, and gneiss. The gravel is relic material formed at a lower stand of sea level during the Pleistocene epoch.

The overall pattern of the bottom material consists of a normal decrease of particle size away from the coast, modified by the areas of relic gravel and rock and fine grained material in a nearshore portion of Redondo Canyon. Silt-sized grains are most abundant in deep water areas of the bay where wave and current action are slight.

The bottom sediments are generally olive-gray color; however, this may vary according to the amount of organic material present. The offshore sand, composed largely of shell fragments, is light olive-gray and is probably being deposited at the present time. Nearshore is detrital sand brought to the bay by streams from the north during the winter and spring. This sand has a more yellow or reddish color than that found offshore.

The average median diameter of the sediments in Santa Monica Bay is 0.116 mm and the range is from 0.005 to 1.05 mm. A plot

of median diameters roughly approximates the bottom material chart in showing a general size decrease away from the shore. There are exceptions in both the central area of rock and gravel and the southern area of organic sand where the diameters are large, and the Redondo Canyon area where they are small. The sediments throughout the entire bay are mostly well-sorted, having an average sorting coefficient of 2.02, although in the canyons and the rock and gravel areas the sorting is relatively poor. Exceptionally good sorting occurs in the nearshore zone where winnowing action by waves carries away the finer particles, and in the nearshore areas where relic sands occur.

The organic carbon content of the sediment ranges from 0.13% to 2.76%, with an average value of 0.90%. The sediment immediately offshore, with the exception of the fine material in Redondo Canyon, has an organic carbon content of less than 0.50%. Exceptions to the general offshore increase in organic content occur in the rock and gravel areas where the values are similar to those of the nearshore sediments. The highest values occur in Redondo Canyon and below the shelfbreak. Thus, there is a progressive increase of organic carbon with depth. This may be a result of less agitation of the particles in the water or of greater deposition of organic matter with finer than with coarser sediments. It is interesting to note that there is no particular increase in organic carbon content in the vicinity of the sewer outfall.

OCEANOGRAPHY NEAR THE OUTFALL AREAS

Salinity

Orange County

From October 22, 1955 to December 20, 1955, the normal salinity of the main body of the shelf water was 33.45 o/oo (Table 3). The

TABLE 3

AVERAGE TEMPERATURES AND SALINITIES AT VARIOUS DEPTHS

ORANGE COUNTY OUTFALL AND VICINITY

Depth Feet	Ave. Temp. °F	Temp. Spread Top - Bottom	Ave. Sal. o/oo
Date: October 22, 1955			
0	61.7		33.41
15	61.3		33.46
30	----		-----
45	58.2	3.5°	33.47
Date: November 4, 1955			
0	62.0		33.45
15	61.2		33.49
30	----		-----
45	59.4	2.6°	33.49
Date: November 18,1956			
0	61.0		33.35
15	60.2		33.46
30	59.7		33.50
45	58.6	2.4°	33.49
Date: December 19 - 20, 1955			
0	58.8		33.37
15	56.1		33.42
30	56.0		33.49
45	56.0	0.8°	33.51

The following figures indicate the overall averages of all samples at each of the depth levels, both with and without the inclusion of the stations in the boil on each cruise.

Depth Feet	Total Number of Samples Average Sal. o/oo	Average Sal. o/oo (excluding boil stations)
15	33.45	33.50
30	33.49	33.50
45	33.49	33.50

salinity in the surface layers varied widely, of course, as the result of dilution by discharge from the outfall. Following the initial dilution, later mixing occurred between effluent and diluted sea water, so that the effects of natural processes were overshadowed by the man-made contribution. An examination of the tables indicates that salinity conditions around the Orange County outfall were relatively simple during this period.

Hyperion

On January 12 and 13, 1956, the salinity of the water around the Hyperion outfall was similar to the noted conditions at Orange County. A surface diluted layer surrounded the boil and a water mass with a uniform salinity formed the bottom layer (Table 4). In addition to data from these two days, oceanographic observations near the outfall taken during routine cruises in Santa Monica Bay show that near Orange County the salinity characteristics are relatively simple and of similar origin.

Whites Point

Data gathered from October 21, 1955 to February 12, 1956 show that salinity conditions in the Whites Point area were more complex than at either Orange County or around the Hyperion outfall (Table 5).

The salinity below approximately 75 feet was fairly uniform with a range from about 33.4 o/oo to 33.5 o/oo. The surface layers, on the other hand, varied widely in response to changes in the adjacent land runoff and to differences in the water masses entering the area. Even so, most of the salinity measurements through the entire water column were within the range of 33.4 o/oo to 33.5 o/oo. Thus, the normal salinity of the water compares

TABLE 4

AVERAGE TEMPERATURES AND SALINITIES AT VARIOUS DEPTHS

HYPERION OUTFALL AND VICINITY

Depth Feet	Ave. Temp. °F	Temp. Spread Top - Bottom	Ave. Sal. o/oo
Date: January 12 - 13, 1956, Hyperion Outfall Area			
0	56.2		33.01
15	55.2		33.33
25	54.2		33.42
45	53.8	2.4°	33.44
Date: January 19 - 20, 1956, Santa Monica Bay Area			
0	55.2		33.51
20	54.4		33.49
40	----		33.49
60	52.8		33.49
80-100	52.9		33.52
120-250	51.7	3.5°	33.60

TABLE 5

AVERAGE SALINITIES VERSUS DEPTH

WHITES POINT AREA

Date	Depth Feet	Ave. Sal. o/oo	High o/oo	Low o/oo	Number
10/21/55	0	33.43	33.46	33.39	10
	15	33.41	33.44	33.37	10
	95	33.45	33.49	33.42	10
11/3/55	0	33.51	33.57	33.35	9
	15	33.50	33.53	33.48	9
	50	33.49	33.51	33.48	8
	115	33.47	33.48	33.44	9
11/17/55	0	33.40	-----	-----	2
	15	33.43	-----	-----	2
	40	33.28	-----	-----	1
	120	33.26	-----	-----	2
2/2/56	0	32.87	32.95	32.84	11
	25	32.85	32.95	32.81	11
	75	33.04	33.21	32.95	11
	125	33.43	33.49	33.30	11
2/3/56	0	33.02	33.13	32.90	4
	25	33.03	33.15	32.92	4
	75	33.20	33.37	33.04	4
	125	33.39	33.44	33.33	4
2/12/56	0	33.34	33.37	33.28	10
	25	33.34	33.37	33.33	10
	75	33.47	33.51	33.37	10
	125	33.47	33.49	33.40	10

Composite salinity average equals 33.31 o/oo

Modal salinity equals 33.42 o/oo

Probable normal surface layer salinity equals 33.4 - 33.5 o/oo

favorably with that in Santa Monica Bay and along the Orange County coast, indicating that the shelf water mass is more or less the same for the entire coast of the Los Angeles Basin.

Salinity changes in the surface layers are probably due mainly to natural causes, although some effect of dilution must occur from the effluent discharge. Because of better mechanical diffusors on the Whites Point outfall than at Orange County or Hyperion, dilution of the sea water is noticeable only in the immediate area of the boil, and not at distances noted in the other areas.

The principal reasons for the variations in the water characteristics near Whites Point are (1) the presence of the adjacent Palos Verdes Hills, and (2) the narrow continental shelf. During the rainy season the hills are a source of runoff which dilutes the nearshore surface water layers. The marked relief and steep slopes promote rapid delivery of rainfall by surface drainage and groundwater percolation. In comparison, the broad flat plains bordering the other outfalls act as reservoirs, tending to absorb the rainfall, or restricting the runoff to local channels.

The narrow shelf allows the offshore currents to come relatively close to shore and introduce different water masses to the outfall area. Such an action does not occur over the broad shelves in Santa Monica Bay and along the Orange County coast. This would indicate that salinity variations would more naturally occur near Whites Point, whereas conditions around the other outfalls should be more stable because of the minor movements of *in situ* water masses.

Temperature Characteristics

Orange County Outfall Area

The temperature distribution immediately around the outfall terminus is complex, as in other discharge areas, with temperature inversions and rapid vertical and horizontal changes in temperature being common. Away from the boil, inversions and temperature fluctuations merge into isothermal water which is characteristic for this period of the year (Table 3).

In the early months of the fall, a marked thermocline was present near the base of the water column, beginning at a depth of about 35 feet and intersecting the bottom. With the approach of winter the thermocline dissipated and from December through February the water was nearly isothermal to a depth of 50 feet. When the thermocline was present it separated the warm mixed surface layer from a thin wedge of cooler subsurface water. The boundary was usually complex being composed of several small thermoclines. These probably represented incomplete mixing of several discrete water layers, either from the effects of the effluent or from surface mixing of different magnitudes in the shallow shelf water. Shear between the two layers probably added to the complexity to varying extents.

The thermocline was most important in its effect on the turbid layer of water developed by the discharged particulate material. When the thermocline was marked and represented a density of discontinuity of some magnitude, the turbid water flowed above the thermocline and carried with it high bacteria populations. With the suppression of the thermocline in the

winter months, there was no particular turbid layer, the material settling to the bottom within a short distance of the outfall.

Whites Point Outfall Area

Temperature distributions in the immediate waters surrounding the Whites Point boil are typical except that the greater diffusion of the effluent prevents the development of the sharp temperature inversions noted at Orange County and Hyperion. The inversions in these waters are spread through a thicker layer of water and the temperature ranges are smaller.

The surface water layer was usually separated from the subsurface water by a marked thermocline which was complex in structure. Turbid layers derived from the sewage discharge were closely associated with the thermocline, but in this area generally below rather than above. As in the other areas, the surface water temperature approaches that of the subsurface water in the winter, eliminating the thermocline and consequently, any discrete intermediate turbid layer (Table 6).

Hyperion Outfall Area

Thermograms from the Hyperion outfall area show similar features to those from the Orange County coastal waters. Temperature inversions are even more striking and extend for greater distances, in some instances being marked as far as three miles from the outfall. Thermoclines were also complex showing the incomplete mixing of several distinct water masses in the diluted zone. Temperature conditions in this water area differ significantly from those near the Orange County outfall. In the latter waters, surface heating in the winter is minor causing the temperature of

TABLE 6

WATER TEMPERATURES IN THE WHITES POINT AREA

Depth Feet	Ave. Temp. °F.	High Temp.	Low Temp.	Temp. Spread Top - Bottom
Date: October 21, 1955				
0	60.2	60.7	59.7	
15	59.5	59.8	59.0	
95	52.1	52.9	51.3	8.1°
Date: November 3, 1955				
0	61.1	61.7	60.8	
15	60.6	61.0	60.2	
50	58.7	61.0	55.8	
115	54.4	57.5	52.0	6.7°
Date: November 17,1955				
0	60.0	60.6	59.4	
15	58.3	----	----	
25	60.1	----	----	
40	57.8	----	----	
115	54.8	55.4	54.3	5.2°
Date: February 2, 1956				
0	55.5	56.7	55.0	
25	54.8	55.4	54.7	
75	54.6	55.0	54.3	
125	52.9	53.7	51.8	2.6°
Date: February 3, 1956				
0	55.7	56.5	55.2	
25	54.7	55.0	54.4	
75	55.3	56.3	54.7	
125	53.8	55.4	53.1	1.9°

the shelf water column to approach isothermal conditions. However, in the Hyperion area the surface water is warmed not only by solar radiation, but also by the large heat contribution from the man-made sources on shore. Thus, the warmer surface layer tends to remain separated from the normal subsurface layer by a moderate to slight gradient or thermocline. Away from the shore and from the warm-water wedge of artificial origin this minor thermocline becomes less marked and finally disappears.

<u>Summary</u>

At none of the outfalls does the thermocline or thermal gradient materially affect the initial rising turbulent effluent column. The degree of mixing of the various columns is marked thermally in all of the areas by inversions and complex temperature gradients. The Whites Point area has weaker temperature gradients due to the better mixing of the effluent with the sea water.

After the initial rise of the effluent column the formation of surface zones of high nutrients and dilution is common to all outfalls, except at Whites Point where the salinity change is slight. At the same time a turbid lower layer forms as the result of sedimentation from the effluent column. The presence of thermal boundaries in the water of sufficient density difference may cause the turbid layer to lie above them. The suppression of these thermal boundaries in the winter months is followed by a marked decline of the turbid layer at higher levels in the water column.

WATER MOTION IN SANTA MONICA BAY

From the data presently available, a generalized description of water motion in Santa Monica Bay can be developed. Ocean

current measurements show that the direction and velocity of flow is highly variable. Current velocities range from 0.1 to 0.4 knot, with about 80% of measurements from all methods being about 0.2 knot. Under some conditions surface velocities may reach a maximum of 0.8 knot. These show a predominant direction between east and south at points near the center of the bay.

On shore in the southern part of Santa Monica Bay are two steam plants, which discharge sea water having a temperature of approximately 80° F. The sewage from the Hyperion Treatment Plant in El Segundo also enters the sea at a temperature of approximately 76° F. The sewage, coupled with the high temperature water from the steam plants, forms a wedge of warm low density water in this nearshore area. It is probably that the density surface generated by this artificially warmed water is sufficient to produce a current flowing in a northerly direction at velocities up to, and in some instances exceeding, 0.4 knot. The velocity and direction of flow changes in the vicinity of Playa del Rey, where afternoon westerly winds may force the flow shoreward between Playa del Rey and Venice. Under no-wind conditions a flow with a much decreased velocity may continue past Santa Monica terminating in the waters off Malibu.

The general surface water motion is controlled by the dominant southwest and westerly winds. The wind driven water is directed shoreward in the central part of the bay and then upon reaching the nearshore zone diverges to the north and to the south. The northerly component when associated with the man-made current frequently causes the sewage to flow through offshore waters as far north as Malibu Point. The southerly component is much less

dominant and frequently forms layers of warm water 10 to 30 feet thick nearshore in the vicinity of Redondo Beach.

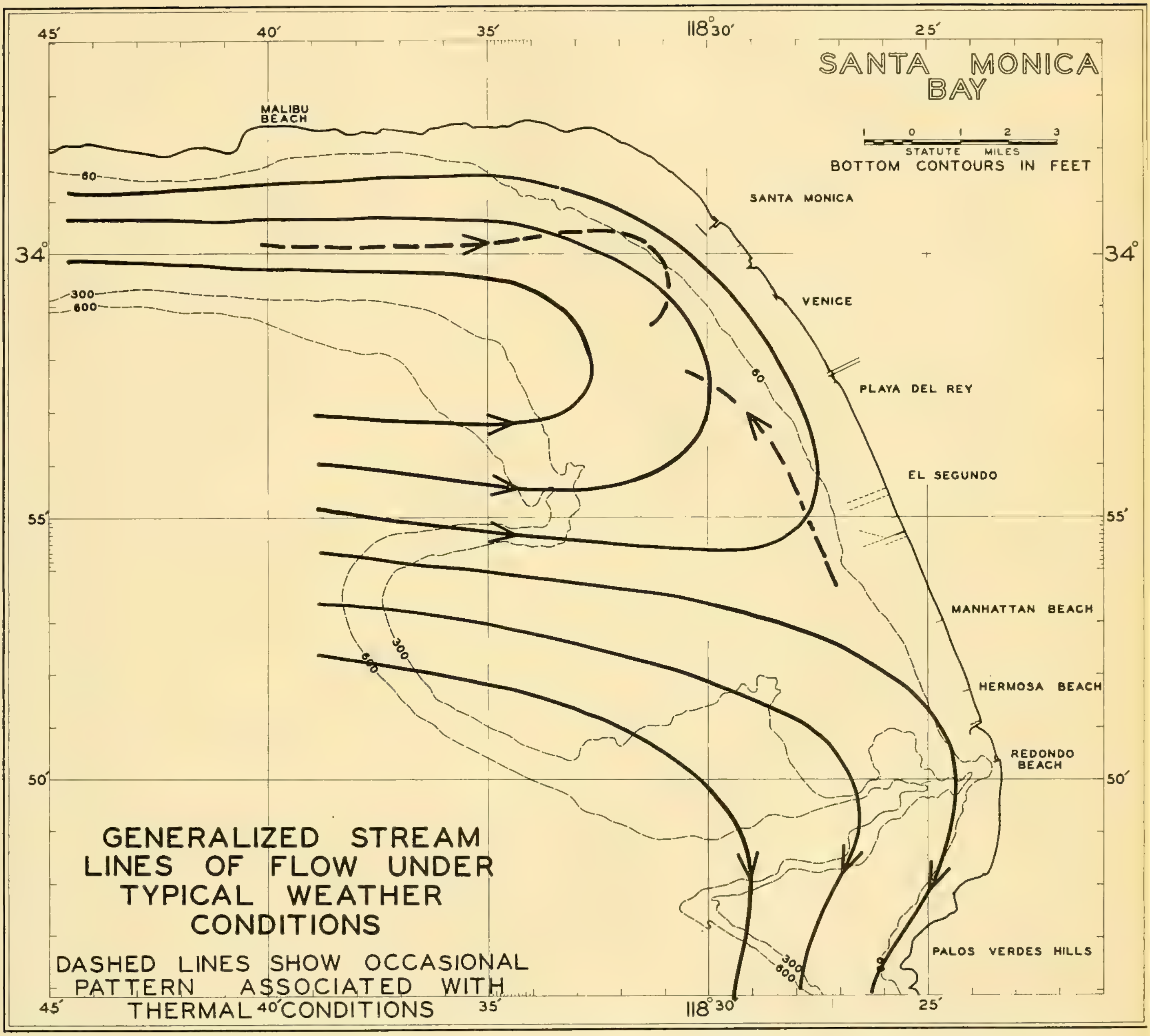
Gentle upwelling along the Malibu coast causes a mild southeasterly directed current which may intersect the northerly flow of the man-made current off Venice. This action on occasion diverts the northerly flowing sewage field in an offshore direction. The diverted flow is mild, not dominant, and does not occur on all occasions (Figure 1).

Frontal storms which enter the southern California area from the northwest result in a southeasterly flow of water over the entire shelf area. These storm conditions completely eliminate the effects of the nearshore wedge of warm water. The changes in water motion caused by storm action are infrequent and last only 2 to 4 days. Thus, the dominant northerly flow of water in a nearshore zone between Redondo Beach and Playa del Rey disappears for only short periods of time.

Because the normal wind and ocean current velocities in Santa Monica Bay are generally low throughout the entire year, the sewage field from the Hyperion Treatment Plant spreads 2 to 3 miles at sea in its northerly flow pattern. However, most of the sewage remains in the nearshore zone where water depths are from 50 to 80 feet. Agitation of the water is normally enough to suspend most of the particulate matter for long periods of time so that it is carried for distances as great as 5 miles. Therefore, with the exception of large dense particles which fall to the sea floor within a few thousand feet of the outfall, deposition of particulate material is extremely slow.

Figure 1

Generalized circulation in Santa Monica Bay.



SANTA MONICA BAY
STATUTE MILES
1 0 1 2 3
BOTTOM CONTOURS IN FEET
MALIBU BEACH
SANTA MONICA
VENICE
PLAYA DEL REY
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
PALOS VERDES HILLS
45′
40′
35′
118°30′
25′
34°
55′
50′
60
300
600
GENERALIZED STREAM LINES OF FLOW UNDER TYPICAL WEATHER CONDITIONS
DASHED LINES SHOW OCCASIONAL PATTERN ASSOCIATED WITH THERMAL CONDITIONS

COLIFORM BACTERIA DISTRIBUTION

Field Procedures

Dye Patch Experiments

Dye patch experiments were used to obtain a direct measure of the rate of disappearance of coliform organisms in the sewage fields. Approximately one pound of fluorescein dissolved in about a gallon of sea water was introduced into the sewage field at the edge of the "boil" above the outfall being investigated. After allowing a few minutes for the dye to become distributed, the zero time sample was taken from within the dyed area. The dyed patch was then followed for three to six hours and samples were removed at intervals. These samples were analyzed for their chlorinity and coliform content.

The dye patches behaved differently during various experiments. In some instances the dyed area remained compact and of limited extent; in others, the dye spread out over a large area, usually in ribbon-like form. The dye was renewed as required to enable continuous observation of that part of the sewage field originally marked. In some instances this required about one pound of dye per hour, in others only the initial pound was required for the four to six hour period. When samples were removed or dye added an effort was made to pick the most concentrated area of the dye patch. On two occasions colorimetric determinations on samples removed from the dye patches were compared against a standard curve set up with measured amounts of fluorescein, and the results indicated that the concentration of dye in the patch did not exceed one part in 10,000.

In some experiments, two independent samples were taken from the same patch and analyzed simultaneously; in others, only a single sample was used. When duplicate samples were used, results agreed very closely. All samples were taken with sterile wide mouth bottles, the water being dipped from the sea surface. Immediately after the samples were obtained, the appropriate dilutions were prepared and the lactose broth tubes for the presumptive test were inoculated. The tubes were placed in the incubator within three hours after inoculation.

Surface and Subsurface Sampling

The areal distribution of coliforms was examined by taking samples throughout the water column in various patterns around the outfalls. The program of sampling varied with the trip and the location of the outfall. In some instances, surface and subsurface samples were collected along the approximate line of sewage flow as determined by the movement of the dye patch. At other times, samples were taken along lines parallel to the coast on both sides of the outfalls, along two lines perpendicular to each other, and along lines repeated morning and afternoon.

Surface samples only were collected along a large triangular course in the vicinity of the Orange County outfall. Surface samples were also collected in a close grid pattern covering small areas in the vicinities of the Whites Point and Hyperion outfalls. In all of these instances, collections were made while the ship was underway and the areas involved were covered in short periods of time.

The vertical sampling series consisted of a surface sample plus two to four subsurface samples and, on some occasions, a

sediment sample. The surface samples were taken with sterile bottles as were the dye patch samples. The subsurface samples were collected with sterile bacteriological samplers (Fig. 2). Water for various chemical determinations was collected at most profile stations; the hydrological and bacteriological casts being interspersed. In all instances, the appropriate dilutions were prepared and the lactose tubes were inoculated and incubated within an hour of obtaining the water samples.

Sediment Sampling

Sediment samples were taken with either a corer or a snapper; the latter being used most frequently because the coarse texture of the sediments near the outfalls made coring difficult or impossible. Immediately after retrieving the sample, a measured portion was suspended in sterile diluent and coliform counts were made on the resulting suspensions. An effort was made to sample only the surface layer of the sediment.

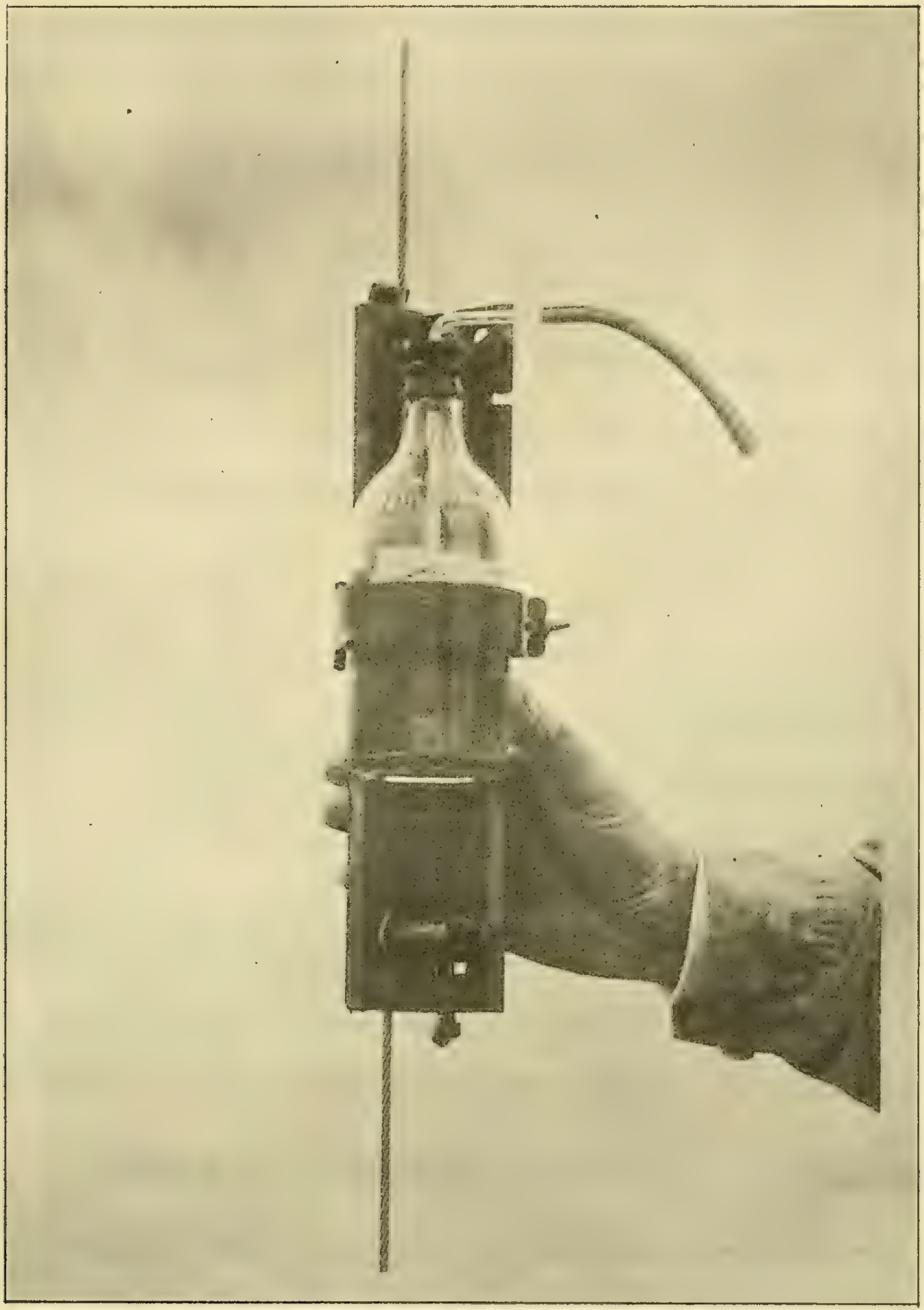
Laboratory Procedures

Determinations of Most Probable Numbers (MPN) of Coliforms

Standard methods were followed in all details for the determination of MPN. Lactose broth and E.M.B. agar respectively were used as the presumptive and confirming media. In general, all positive presumptive tubes in the three highest dilutions showing positives were confirmed. All negative confirmed tests were completed. Six dilutions to 10^{-5} were prepared from almost all of the water samples examined and consequently most tests were determinate. Four dilutions, 10^{-1} to 10^{-4}, were used for

Figure 2

Bacteriological water sampling device.



most sediment samples. Five lactose broth tubes were used for each dilution in the dye patch experients and two tubes per dilution were used for other types of samples.

Identification of Coliforms

For conclusive identification of coliforms, typical colonies were picked at random from positive confirmed plates and checked morphologically and biochemically by Gram-staining and by the Imvic tests. Several dozen colonies thus check proved to be species of either Escherichia or Aerobacter.

Enteric Pathogens

An effort was made on two occasions to isolate enteric pathogens from the sediments around the Hyperion outfall. About one gram of mud was introduced into tetrathionate broth and the cultures incubated at 37°C for 24 hours. These enrichment cultures were then streaked on S.S. agar plates. Suspicious colonies appearing on these plates were transferred to triple sugar iron medium. Tests were not continued beyond this stage because all colonies examined proved negative for pathogens.

Disappearance of Coliforms With Time (Dye Patch Experiments)

A total of sixteen dye patch experiments were conducted; twelve at the Orange County outfall, three at Whites Point, and one at Hyperion. Of the sixteen experiments, thirteen showed a marked and usually consistent disappearance of coliforms with time. These will be discussed as a group. The three "atypical" experiments will be dealt with separately.

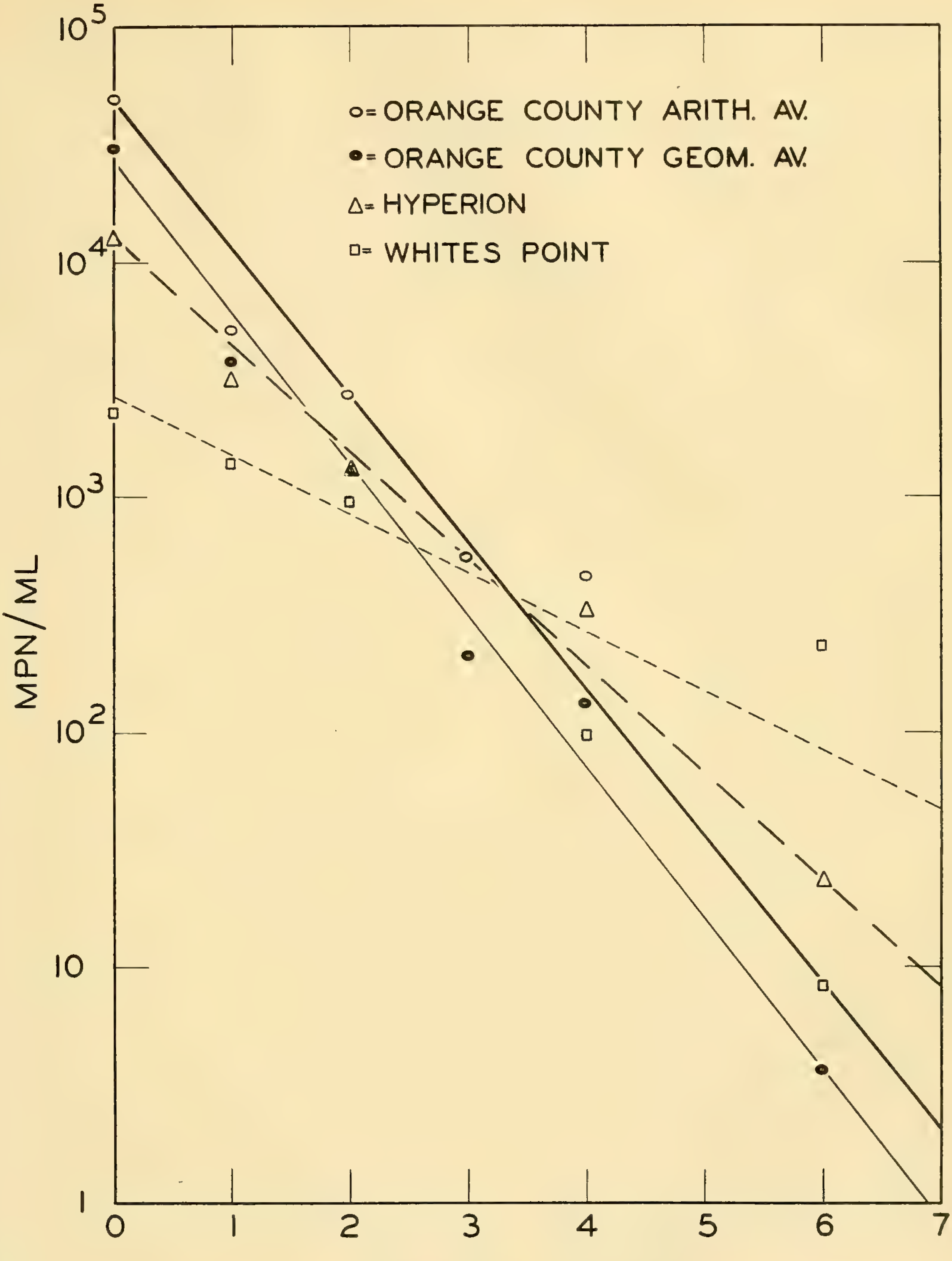
Estimated "best fit" curves drawn through the arithmetic and geometric averages of the dye patch data collected at Orange County, plotted as the log of the most probably number of coliforms per ml against time are shown in Figure 3. The points fall surprisingly close to a straight line using either means of plotting, and the slopes of the lines are essentially the same.

The other two curves on the graph are plots of individual dye patch experiments at Hyperion and Whites Point. The rate of decrease of coliforms was less than at Orange County in both cases, although the slope of the Hyperion curve is not greatly different. The Whites Point experiment differed from the others in two important ways, both of which may have contributed to the less rapid disappearance observed. First, the zero time count was lower by a magnitude or more than in the other dye patch experiments. Since this count was also lower than that of other samples taken in the Whites Point boil, it might not be representative of the dye patch and an initial sharp decrease may have been masked. Second, the dye patch was started at the edge of the inner boil and the patch of travel was such that it intersected "younger" sewage being released at the outer boil. This could mean that the dye patch was being mixed with water of higher coliform count which would explain the slower decline in coliform numbers.

Of the three "atypical" sets of results, one was from an Orange County experiment in which the zero-time count was low and the chlorinity data showed little sewage present in the water. In this instance it can be concluded that the dye was introduced into an unrepresentative part of the boil and the results of this experiment should be eliminated. The other two atypical results were in

Figure 3

Diagram indicating decrease in coliforms with time in connection with dye patch experiments at Orange County, Whites Point, and Hyperion outfalls.



DECREASE IN COLIFORMS WITH TIME DYE PATCH EXPERIMENTS

experiments run on two succesive days at Whites Point. High coliform counts persisted for the full six hours in one instance, and for two hours in the other. The chlorinity data show that a high percentage of sewage was present in all samples and that the dilution usually noted in dye patch experiments did not occur. Further, field observations showed that the dye patch, started at the inner boil, was reinforced with sewage from the outer boil during the experiment. Both of these observations suggested that conditions exist in which the expected decrease might not occur. Unfortunately, an accident occurred in which the plugs of all the presumptive tubes in these experiments were thoroughly wetted with polluted water and contamination of the lactose broth was possible. Consequently, no reliance can be placed on these data.

From the data, one would predict a one to four magnitude disappearance of the surface coliform population in about six hours for the types of conditions and types of sewage represented in these experiments. Disappearance was most rapid at Orange County and least rapid at Whites Point with Hyperion intermediate. In terms of per cent reduction, with the boil population taken as 100%, the values would be 99.98% for Orange County, 99.90% for Hyperion, and 90% for Whites Point. Using the coliform count of the effluent being discharged as 100%, the per cent reduction for Orange County would be 99.9993%. Since the same type of picture was obtained repeatedly at Orange County, it is probable that the results are representative; the other curves being based on single experiments are only suggestive.

Effect of Dilution

One of the factors responsible for the decrease in coliforms with time in the dye patch experiments is certainly the dilution of the sewage effluent with normal sea water. Since the chlorinity of the sewage is low as compared to that of sea water, and since the chlorinity determination is accurate to about four significant figures, it is possible to determine dilutions of sewage out to about one part in several hundred. Assuming that coliform bacteria act like a dissolved solute, one can calculate the expected coliform count from a knowledge of the chlorinity and coliform count of the sewage, the chlorinity of the sample, and the normal chlorinity of the sea water in the area. The latter value varies over a small range and this variation introduces uncertainties into the calculations, especially at the higher dilutions. The coliform content and chlorinity of the effluent vary widely. Consequently, the calculated dilutions are not precise. Nevertheless, they should indicate the magnitude of disappearance due to this factor.

The calculated and observed coliforms in the zero time samples taken from the edge of the boil at Orange County are shown in Table 7. The calculations are based on 25 samples of sewage collected on three separate days at the junction of the land and marine sections of the outfall, and on five dye patch experiments run on the corresponding days. There is a very close agreement between the average calculated MPN and the observed range of counts found in the zero time samples. This correspondence of results indicates that essentially all coliforms rise to the ocean surface at the point of discharge.

TABLE 7

CALCULATED VERSUS OBSERVED COLIFORM COUNTS IN ZERO-TIME SAMPLES BASED ON A NORMAL SEA WATER CHLORINITY OF 18.59%

	Effluent Sewage			Zero Time Samples		
	Ave.	Max.	Min.	Ave.	Max.	Min.
CI o/oo	2.212	4.200	1.190	17.97	18.11	17.90
Coliforms/ml	$1.3x10^6$	$3.5x10^6$	$0.13x10^6$			
Calculated % sewage				3.79	4.72	2.83
Calculated dilution sewage				1/26.4	1/35.4	1/21.2
Calculated coliforms/ml				$4.94x10^4$	$1.5x10^5$	$5.0x10^3$
Observed coliforms/ml				$2.4x10^4$	$3.5x10^4$	$1.8x10^4$

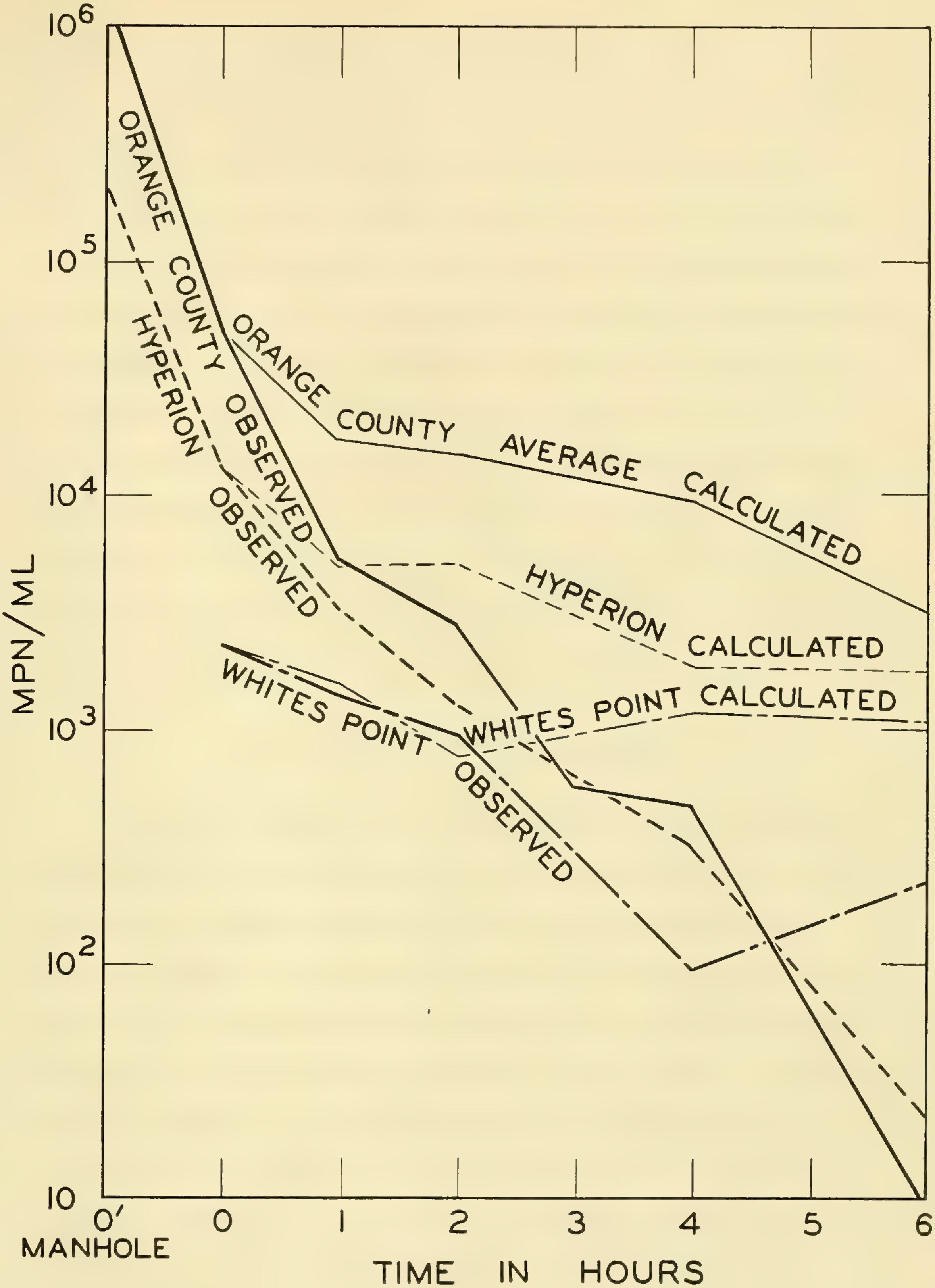
Similar computations were made on the basis of chlorinity determinations on dye patch samples taken subsequent to zero time. The data are presented in Figure 4. The upper line represents the average calculated counts and the lower line the average observed counts for all the Orange County data. It can be seen that the average observed counts at all times after zero time are considerably less than the calculated counts; differing by one magnitude at about two hours, and $2\frac{1}{2}$ magnitudes at six hours. These data show that other important factors besides dilution are contributing to coliform disappearance.

Unfortunately, comparable information is not available for the initial coliform population and chlorinity of the Hyperion and Whites Point effluents. Data provided by the Hyperion and Whites Point personnel indicate an average chlorinity for these two effluents of about 0.26 and 1.0 o/oo respectively and our own data show an average normal chlorinity for the surface waters of these areas of about 18.55 o/oo. Using these values, a dilution of 1/17 was calculated for the boil sample in the successful Hyperion dye patch experiment. Initial dilutions of up to 1/40 have been found for other samples taken from the Hyperion boil. As with the Orange County experiments, the observed counts at Hyperion were less than the calculated counts at all times after the zero point value and the difference at the end of six hours was of the order of two magnitudes (Fig. 4).

The initial dilution of the sewage in the zero time sample at Whites Point was higher than at the other two outfalls, being 1/84. This might have been expected since the Whites Point outfall is the only one of the three with a large diffuser. On

Figure 4

Diagram showing MPN of coliforms in the vicinity of three outfalls calculated from dilution of sewage and observed *in situ*.



MPN OF COLIFORMS IN THE VICINITY OF THREE OUTFALLS CALCULATED FROM DILUTION OF SEWAGE AND OBSERVED IN SITU

other occasions, however, samples taken in the vicinity of the outfall showed initial dilutions as low as 1/33. It is probable that oceanographic conditions and sewage discharge rates vary sufficiently to produce marked fluctuations in the initial degree of mixing. The calculated counts followed the observed counts for the first two hours of the Whites Point experiment and then started to digress. The final difference was somewhat less than those at the other outfalls, amounting to only a magnitude (Fig. 4).

The three sets of data are thus qualitatively alike although quantitatively different. They show that the maximum effect of dilution on the coliform population occurs during the initial mixing of the effluent with sea water as it leaves the outfall, and any further reduction in MPN due to dilution is slow.

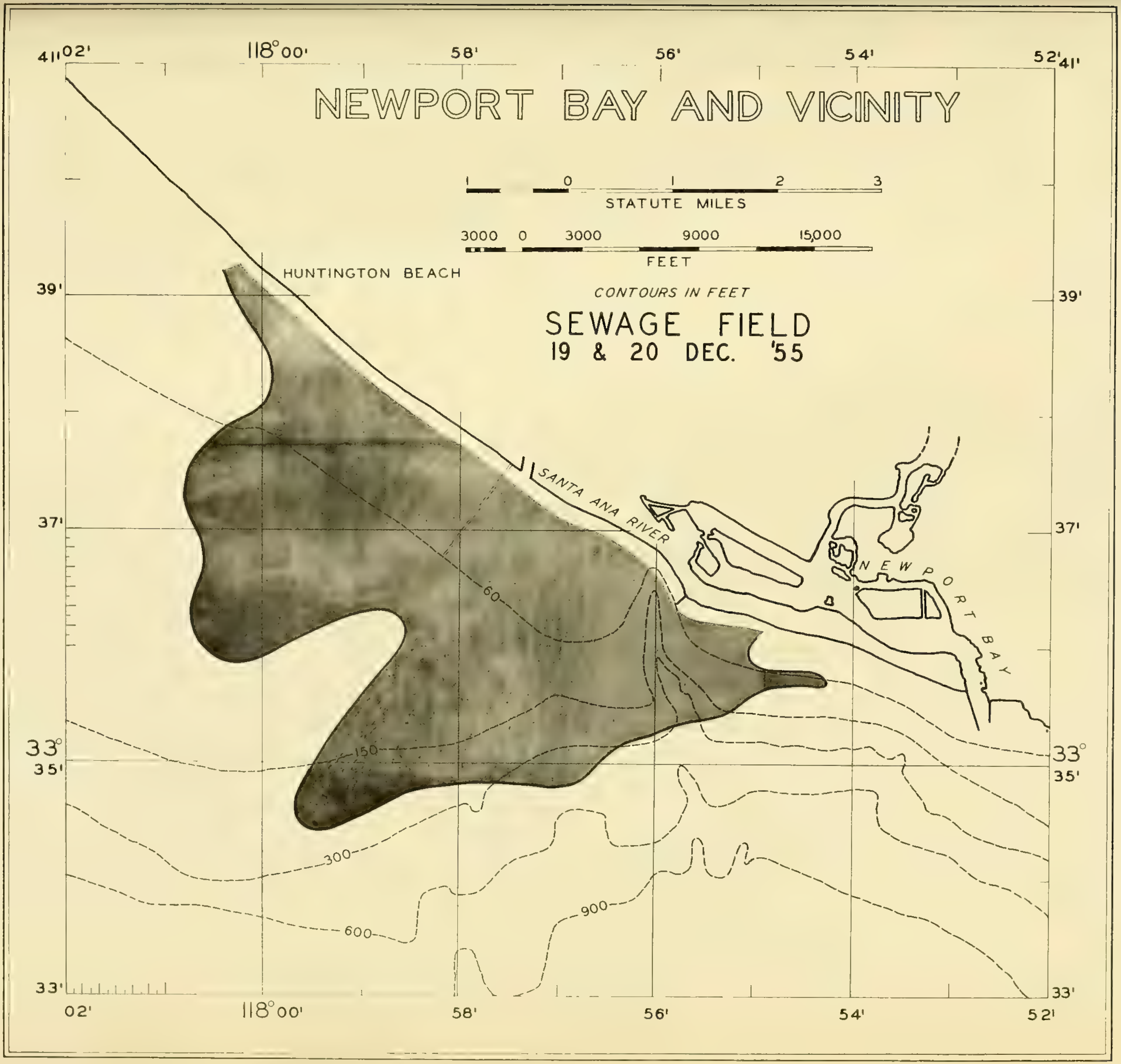
Surface Distribution of Coliforms

The surface sewage field around the Orange County outfall as determined by coliform detection is outlined in Figure 5. The picture is a composite based on all the surface samples taken from the VELERO IV on the four trips to this area, plus a series of inshore samples collected by personnel of the County Sanitation District of Orange County on December 19 and 20, 1955. The shaded portion represents the area within which all positive samples of any magnitude are contained. The field drawn should not be considered a static picture of the area of detectable sewage, but rather as a rough boundary beyond which coliforms should not usually be found.

The same surface data, when plotted as the log of the coliform count against distance from the outfall, independent of

Figure 5

The horizontal distribution of the sewage field in the waters surrounding the Orange County sewer outfall on December 19 and 20, 1955.

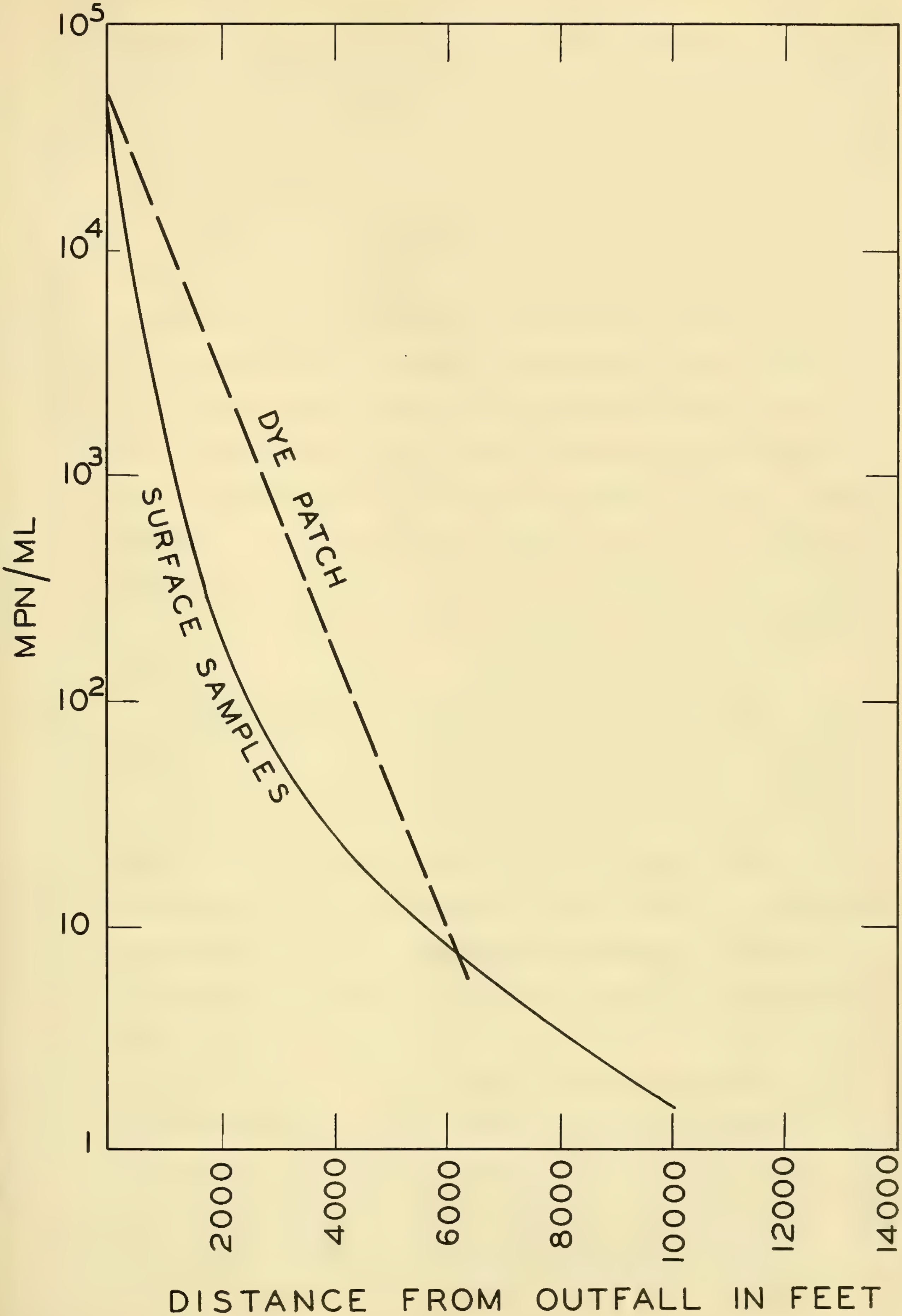

NEWPORT BAY AND VICINITY
STATUTE MILES
FEET
CONTOURS IN FEET
SEWAGE FIELD
19 & 20 DEC. '55
HUNTINGTON BEACH
SANTA ANA RIVER
NEWPORT BAY
60
150
300
600
900
118°00'
58'
56'
54'
52'
02'
41'
39'
37'
33° 35'
33'

direction, gives the "best fit" curve shown in Figure 6. This curve shows a decrease in coliforms to about ten per ml in a distance of 6,000 feet from the outfall. Of the 35 samples taken from the VELERO IV at greater distances from the point of sewage discharge, none gave counts of over 10 per ml. An inspection of Figure 3 shows that the average coliform counts in the dye patch experiments decreased to about 10 per ml in roughly six hours. If one assumes that the sewage field is moving at the rate of 1,000 feet an hour (0.2 knot), a value that roughly corresponds to the observed rate of movement of the dye patches, then there is a good correspondence between the dye patch data and the surface sample data. Plotting the dye patch data on the basis of this assumption gives a curve (Fig. 6) that is somewhat higher than the surface distribution curve. Since the surface distribution curve is based on some points that were probably not in the main sewage field, one would expect it to show a more rapid decrease than that found along the main direction of sewage flow as measured by the dye patches.

No attempt was made to map the surface field around either the Whites Point or Hyperion outfalls, but surface samples were taken with the vertical profiles in these areas. The data show a decreased count with distance, although the results were more variable than at Orange County and the rate of decrease was not as rapid. Thus, counts greater than 2,000 per ml were found 9,000 feet away from the Hyperion outfall and counts of greater than 200 per ml were observed 12,000 feet from the Whites Point outfall. In the area of the latter outfall, visible patches of greasy slicks were observed on the sea surface as much as four

Figure 6

Coliform count versus distance from the outfall plotted with average coliform counts in dye patch experiments. Orange County sewer outfall, December 19 and 20, 1955.



10^5
10^4
10^3
10^2
10
1
MPN/ML
DYE PATCH
SURFACE SAMPLES
2000
4000
6000
8000
10000
12000
14000
DISTANCE FROM OUTFALL IN FEET

or five miles from the outfall. These slicks apparently do not disperse nor break up rapidly and the occurrence of high counts at great distances from the point of sewage discharge may relate to their presence.

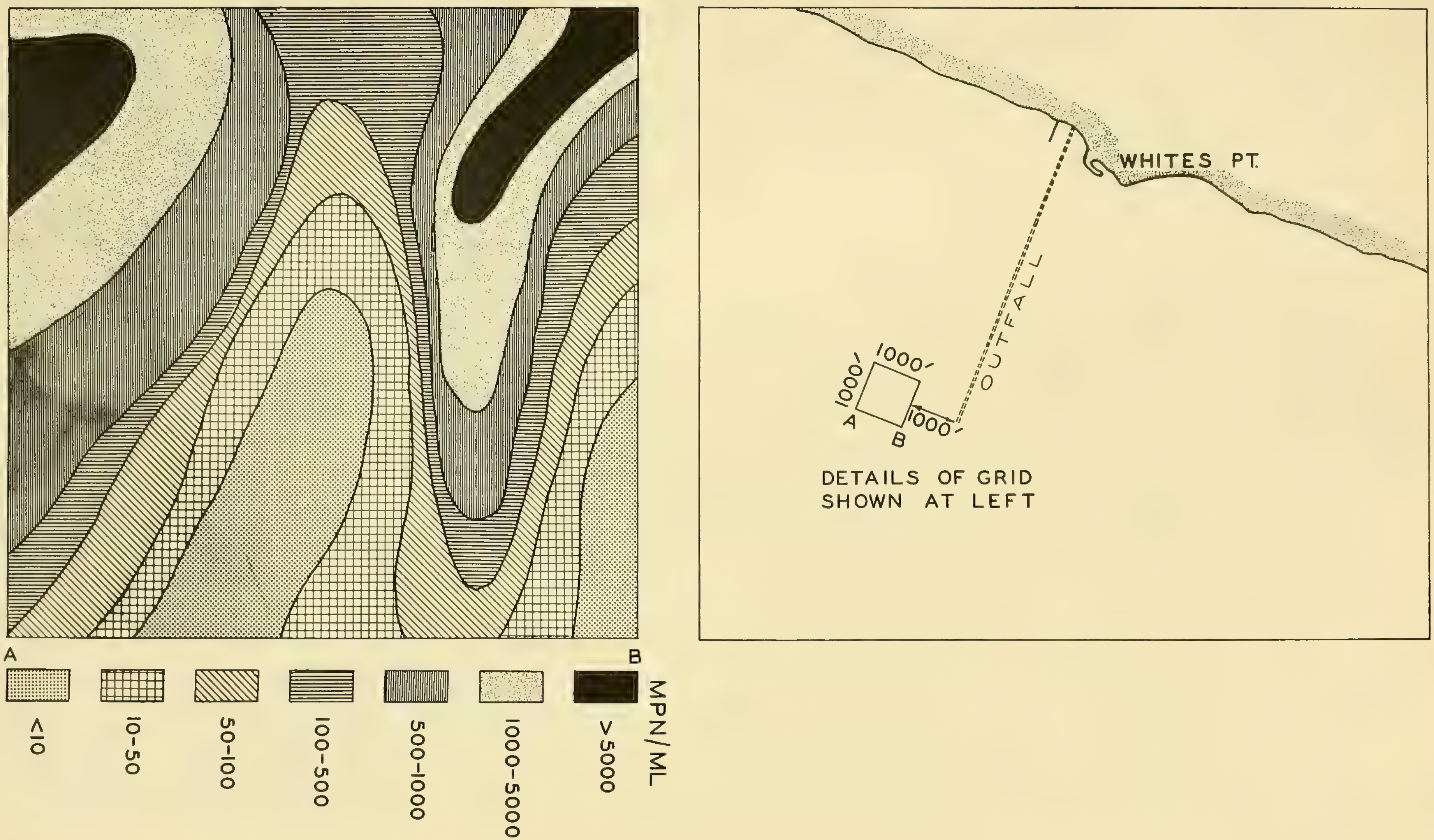
That coliforms are not uniformly distributed in the surface waters even within the main sewage field is clearly seen from the results of three experiments in which surface samples were collected over a small area within the main sewage field. The first of these experiments was run at Whites Point where a grid of 23 samples covered a square about 1,000 feet on a side located roughly 1,000 feet up coast from the outer Whites Point boil. The position of the grid overlapped the path of travel of a dye patch started at the inner boil some five hours previously. The location of the grid is shown in Figure 7; the counts obtained on the grid samples are the basis of the contours also shown in Figure 7.

From the extreme variation in the counts observed (Fig. 7 and Fig. 12), one might conclude that the boat was passing in and out of the sewage field during the collection of the samples. However, calculations based on the chlorinities of the samples showed that the per cent sewage varied only $2\frac{1}{2}$ fold, from 0.46% to 1.02%, making this argument invalid. From the per cent sewage and the MPN of the samples, the original of "100% sewage count" can be calculated (Table 8).

It can be seen that the highest "100% counts" are within the range of what might be expected for an unchlorinated primary effluent, suggesting that no mechanisms are at work that might tend to concentrate coliforms as compared to the liquid phase of sewage. On the other hand, the low "100% counts", and there are

Figure 7

Location of Whites Point grid and the distribution of surface coliforms within the grid.



DISTRIBUTION OF SURFACE COLIFORMS AT WHITES POINT

FEBRUARY 3, 1956

TABLE 8

CALCULATED "100% SEWAGE COUNTS"

FROM WHITES POINT GRID SAMPLES (MPN/ML)

Sample Number	Per Cent Sewage	Observed Count	Calculated 100% Count
1	.74	.6	81
2	.63	.6	96
3	.86	nil	- - - -
4	.80	23	2,900
5	.46	230	50,000
6	.69	6,200	900,000
7	.63	620	99,000
8	.57	6,200	1,100,000
9	.69	2,300	340,000
10	.86	620	73,000
11	.57	230	4,000
12	.57	.6	100
13	1.02	6.2	600
14	.97	62	6,500
15	.74	230	31,000
16	.91	2,300	250,000
17	.86	1,300	150,000
18	.86	620	73,000
19	.69	62	9,000
20	.86	6.2	700
21	.51	1,300	250,000
22	.69	6,200	900,000
23	.57	2,300	400,000

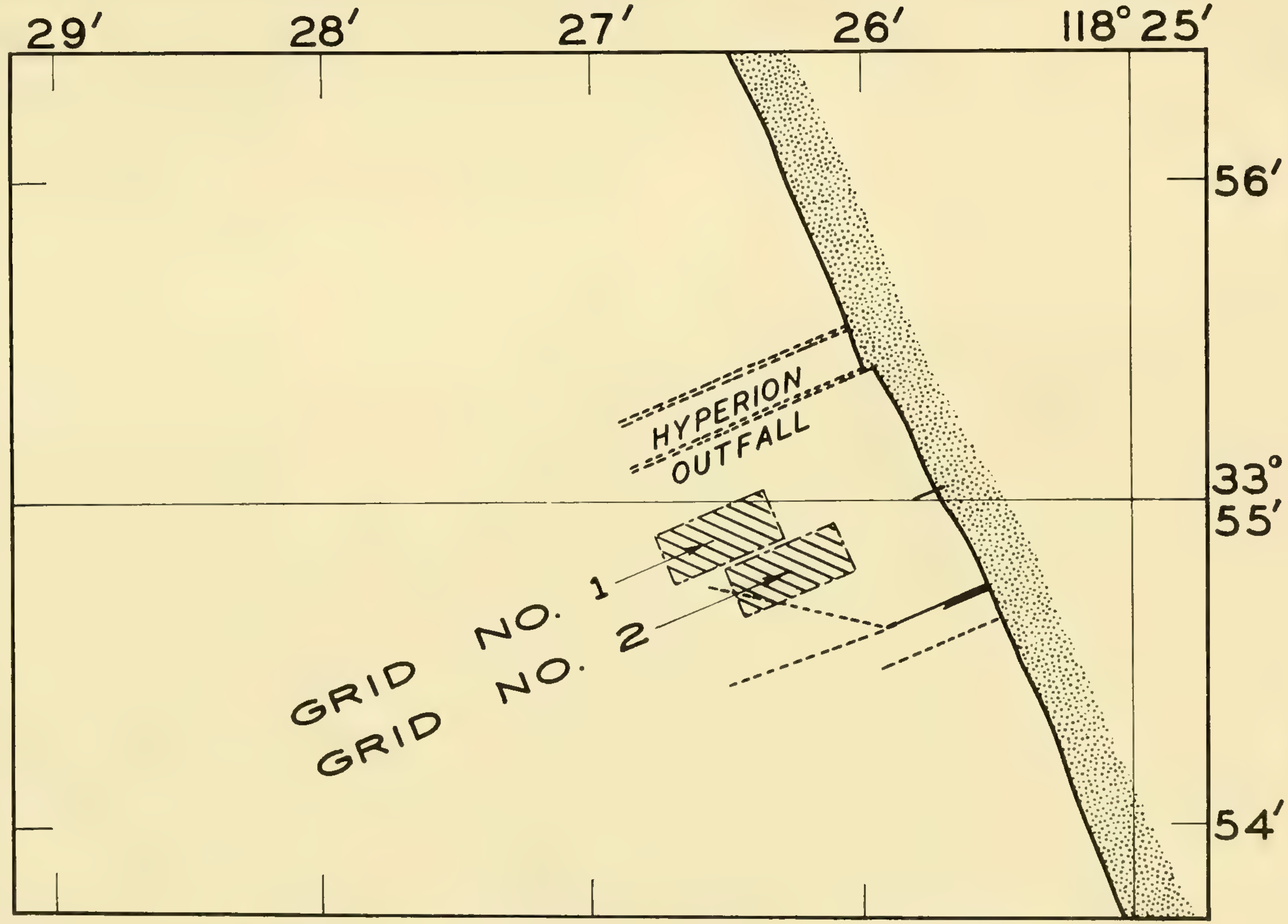
many of them, are far below a reasonable value for a primary effluent. These low values show that coliforms disappear much faster than the liquid sewage phase and reinforce the conclusion from the dye patch experiments that factors other than dilution play a major role in coliform disappearance.

The median count for the 23 samples is 73,000 per ml. If one accepts the maximum "100% counts" (1,000,000 per ml) as the average of the plant effluent, then one can conclude that about 93% of the initial coliform population had disappeared for causes other than dilution in the time (or distance) of travel from the outfall to the area of the grid. On the other hand, one must also conclude that individual patches of sewage will show essentially no reduction in counts beyond dilution over the same path of travel.

Two similar grids were run in the vicinity of the Hyperion outfall on March 8, 1956. The grids were located between two dye patches started almost simultaneously on opposite poles of the boil and were rectangular in shape, being about 1,000 by 2,000 feet on the sides (Fig. 8). The first was about 1.6 hours travel from the outfall, the second about 4 hours (Fig. 9). Although the range of counts in these two grids was about as great as that observed at Whites Point (210/ml to 70,000/ml for grid one; 62/ml to greater than 70,000/ml for grid two), there was a much more uniform distribution of coliforms (Fig. 9). This is also shown in Figure 10 in which the per cent of the total samples giving a particular count is plotted against the log of the count. Almost 50% of the counts in the first grid were the same and a large share of the other values represent differences

Figure 8

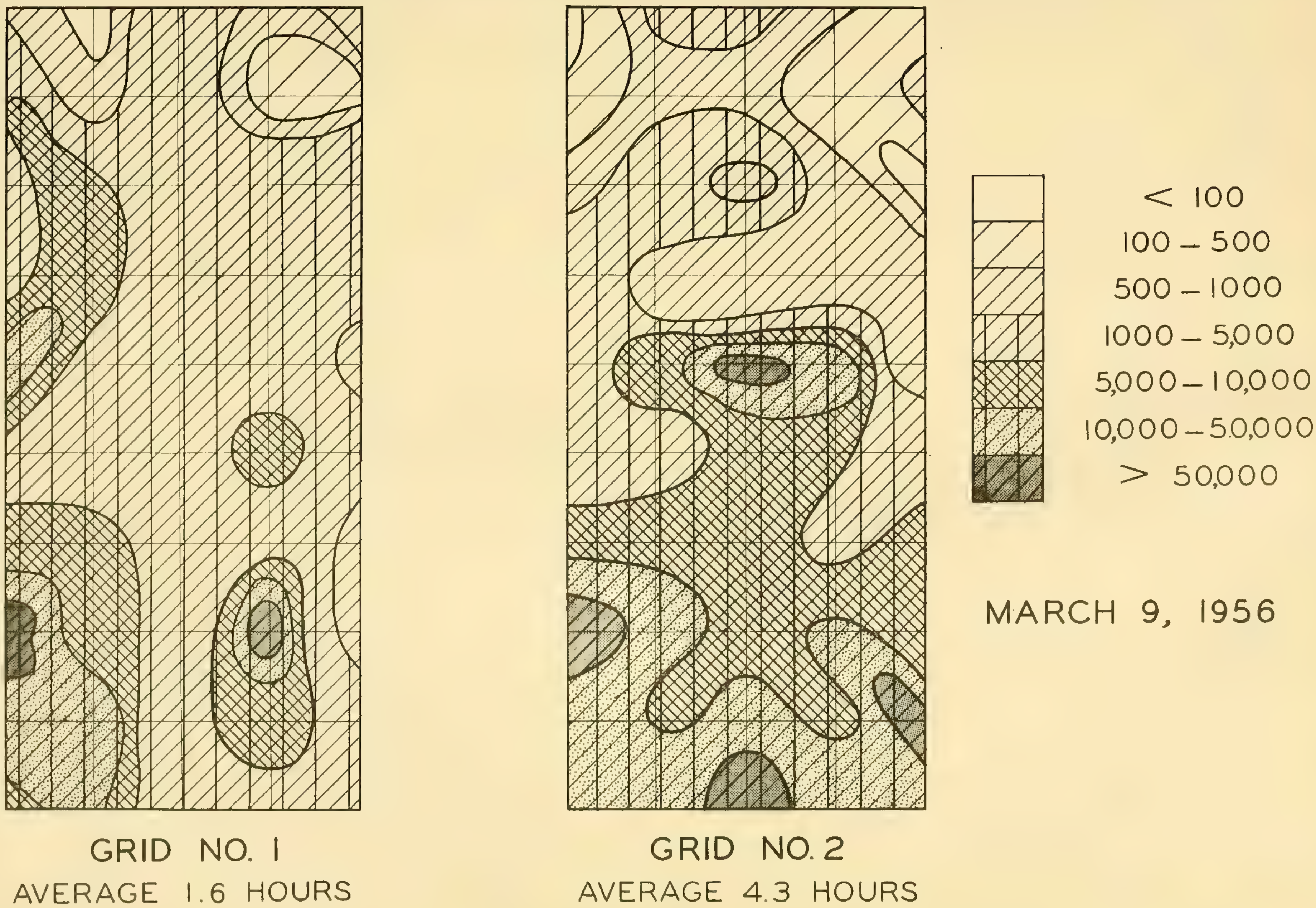
Locations of Hyperion grids on March 9, 1956.



LOCATION OF GRIDS – SURFACE
COLIFORM DISTRIBUTION
HYPERION OUTFALL — MARCH 9, 1956

Figure 9

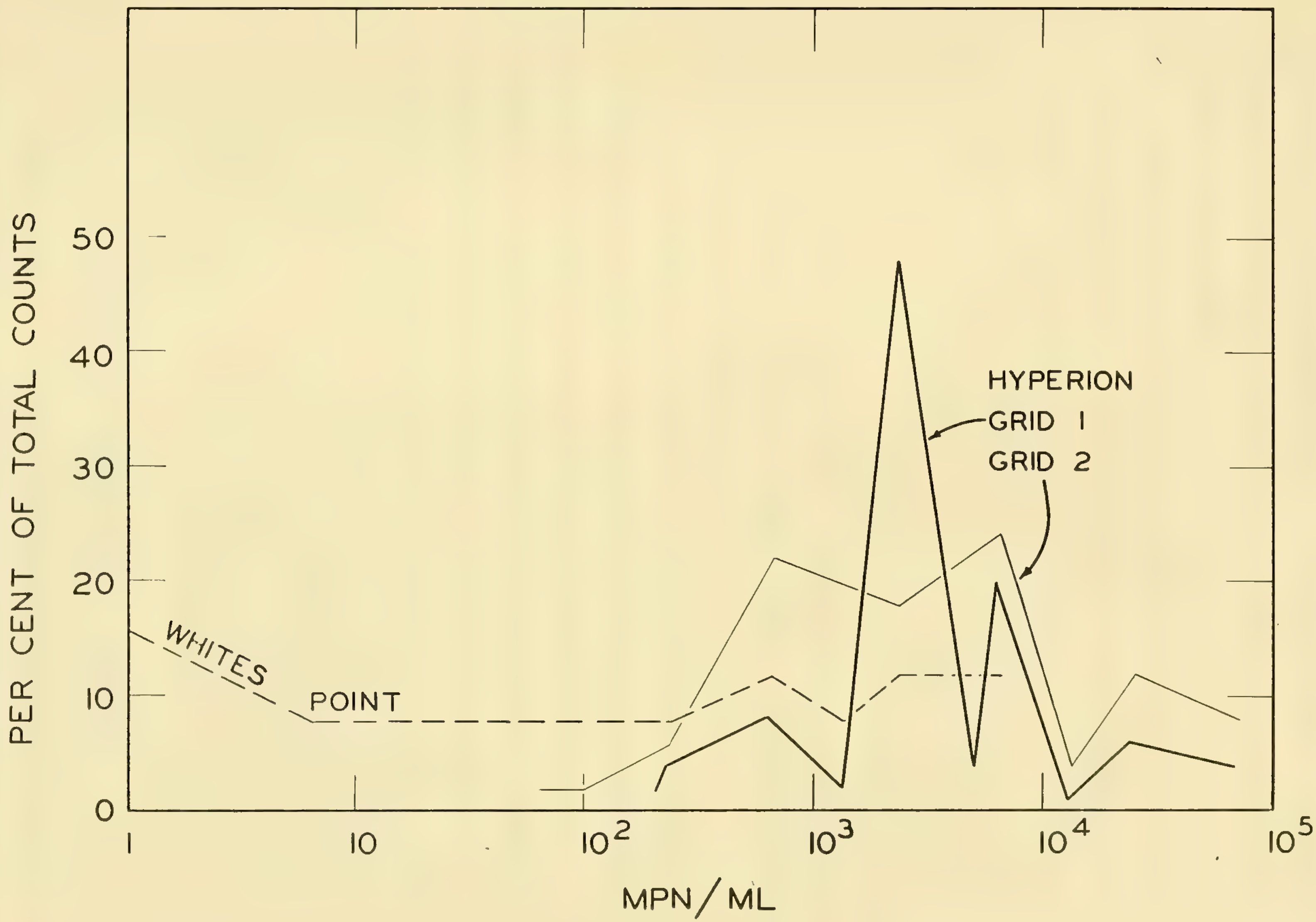
Surface coliform distribution on grids near Hyperion outfall on March 9, 1956.



SURFACE COLIFORM DISTRIBUTION NEAR HYPERION OUTFALL

Figure 10

Distribution of counts in grid samples.



DISTRIBUTION OF COUNTS IN GRID SAMPLES

of only a single positive tube in the presumptive tests. The results of the second grid were a little more variable than the first, but here also, over 60% of the counts were concentrated within a narrow range.

There is no evidence of any significant loss of coliforms from the sewage field in the time elapsed between the two grid samplings near Hyperion. Actually the average MPN for the second grid, 11,500, was somewhat higher than the average for the first grid, 7,100; more significantly, the median values were 2,300 for the first and 4,300 for the second, and the geometric averages were 3,100 and 3,300 respectively. However, there was a considerable reduction in count between the samples taken in the boil and those from the grid 1.6 hours later.

A comparison of the data from the two grids with that of the earlier dye patch experiment shows that similar counts were obtained at 0 and 2 hours, but that the counts continued to decrease in the dye patch whereas the grids showed no further decrease over the next two hours. Of the 50 four-hour grid samples run, five (10%) had MPN lower than the dye patch sample at corresponding time and 11 (22%) had just slightly higher MPN. Thus, the data from the dye patch experiment, although not necessarily reflecting the average behavior of the sewage field, was certainly typical of part of the sewage field.

Subsurface Distribution of Coliforms

Approximately 30 vertical stations were occupied during four trips to the Orange County area; 30 stations on two days at Whites Point and 20 on two days at Hyperion. Typical results are shown

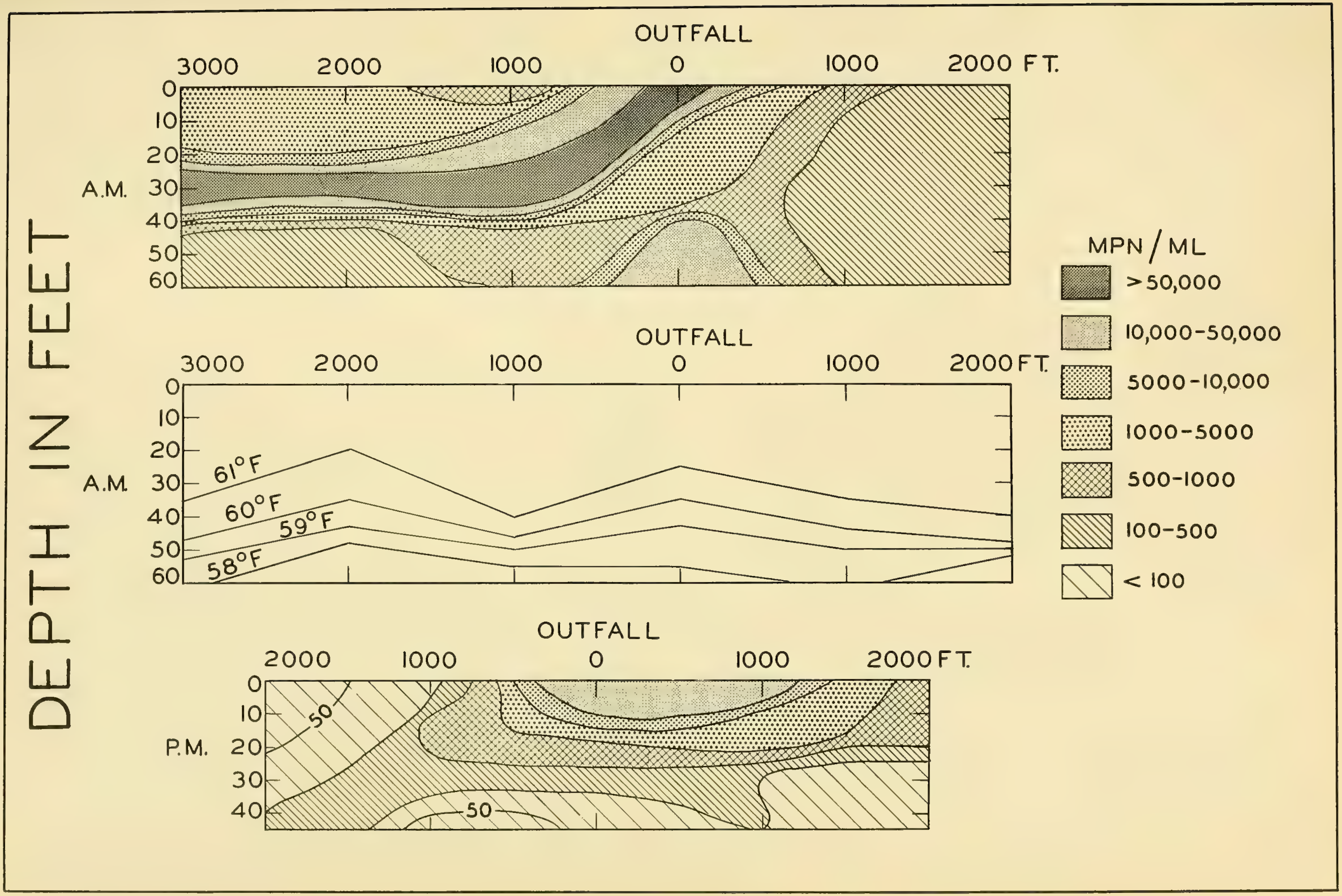
in Figures 11, 12, and 13. Considering the vast volume of water being sampled in these series and the very small numbers of samples that could be taken, it is certain that the profiles presented cannot be considered as an exact representation of the subsurface distribution of coliforms. Nevertheless, certain features of the profiles appear repeatedly in the various series and suggest two general conclusions.

The first of these is that the highest subsurface counts occur along the general lines of surface movement of the sewage field. For example, Figure 11 shows two profiles obtained on the morning and afternoon of the same day. In the morning, the surface sewage field was moving upcoast, while the direction was reversed in the afternoon. It can be seen that the subsurface MPN reflect this altered movement. The Whites Point profile of November 3 and the Hyperion profile of January 12 show the same effect; high subsurface counts in the direction of surface movement, and essentially zero counts in the opposite direction. Such a pattern could result in at least two ways; either by assuming a uniform direction of movement of the water at all levels with subsurface as well as surface sewage flow, or else by assuming all sewage rises and flows at the surface only and subsurface coliforms represent sedimentation from the surface field.

The repeated occurrence of tongues of high coliform count extending downward from the surface provide evidence for sedimentation as the major factor determining subsurface coliform distribution. Such a tongue is clearly seen in the profiles in Figure 11, 12, and less prominently in Figure 13. It is quite clear in Figure 14, which presents an average of all the profile

Figure 11

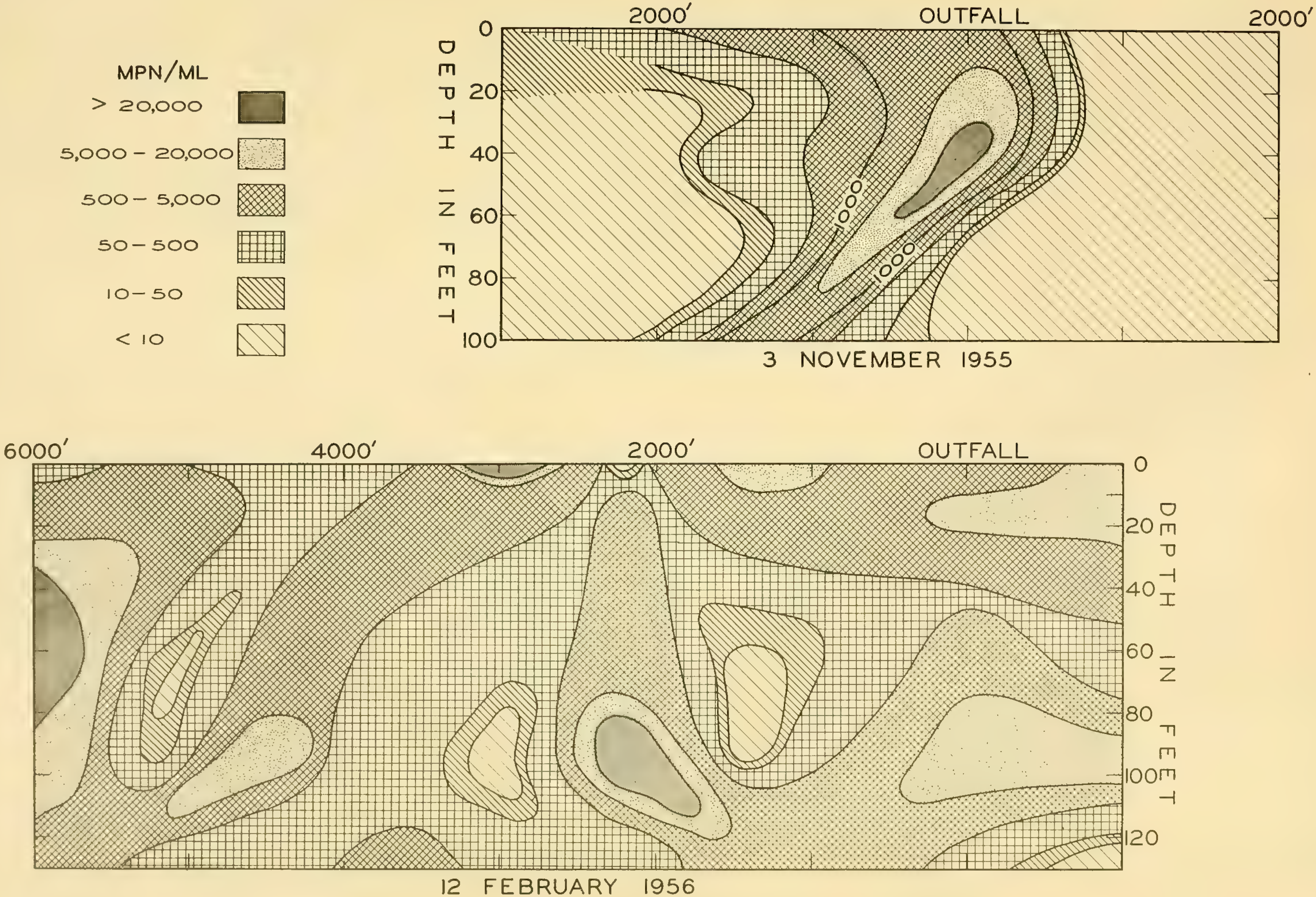
Typical bacteria and temperature profiles extending parallel to shore in the waters surrounding the Orange County sewer outfall on December 19 and 20, 1955.



DEPTH IN FEET
OUTFALL
3000
2000
1000
0
1000
2000 FT.
0
10
20
30
40
50
60
A.M.
61°F
60°F
59°F
58°F
P.M.
50
MPN / ML
> 50,000
10,000-50,000
5000-10,000
1000-5000
500-1000
100-500
< 100

Figure 12

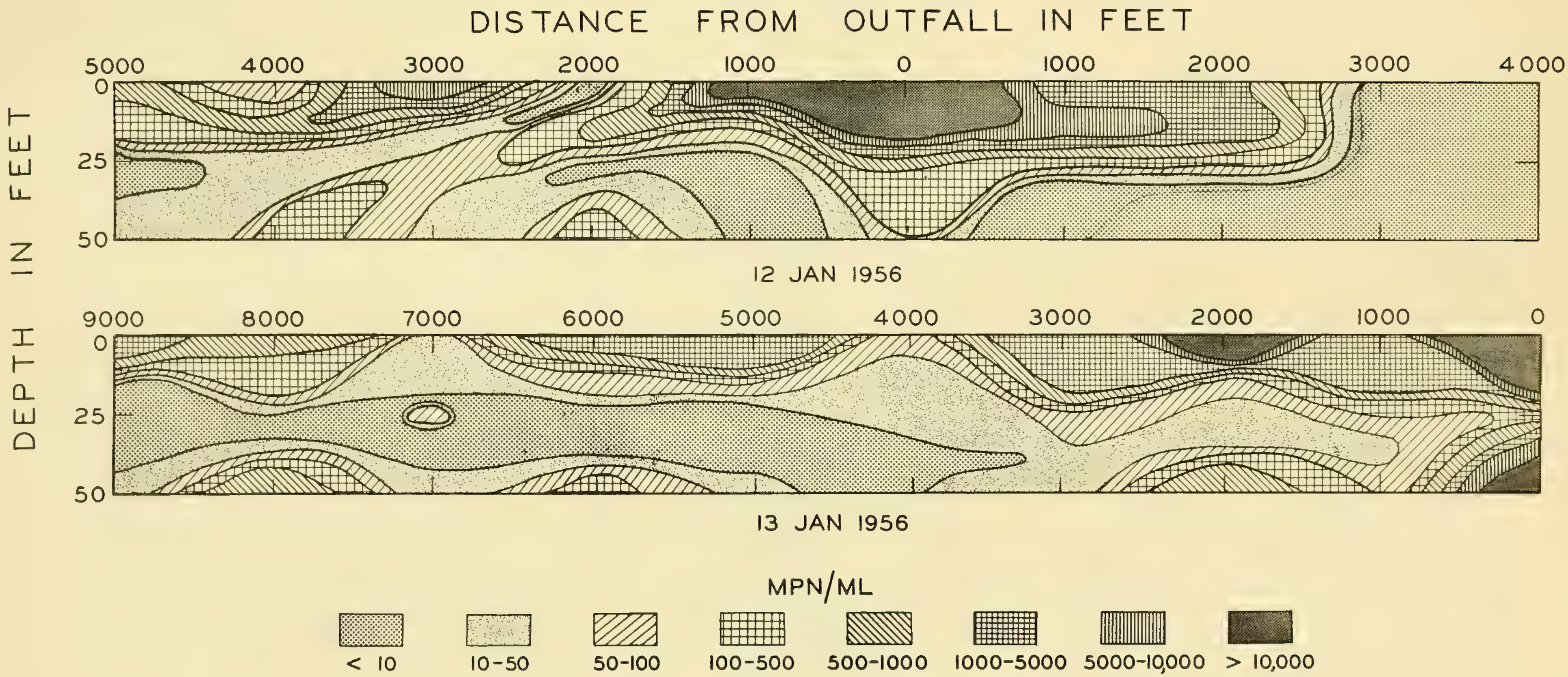
Bacteria profiles extending parallel to shore in the waters surrounding the Whites Point sewer outfall on November 3, 1955 and February 12, 1956.



COLIFORMS MPN/ML AT WHITES POINT

Figure 13

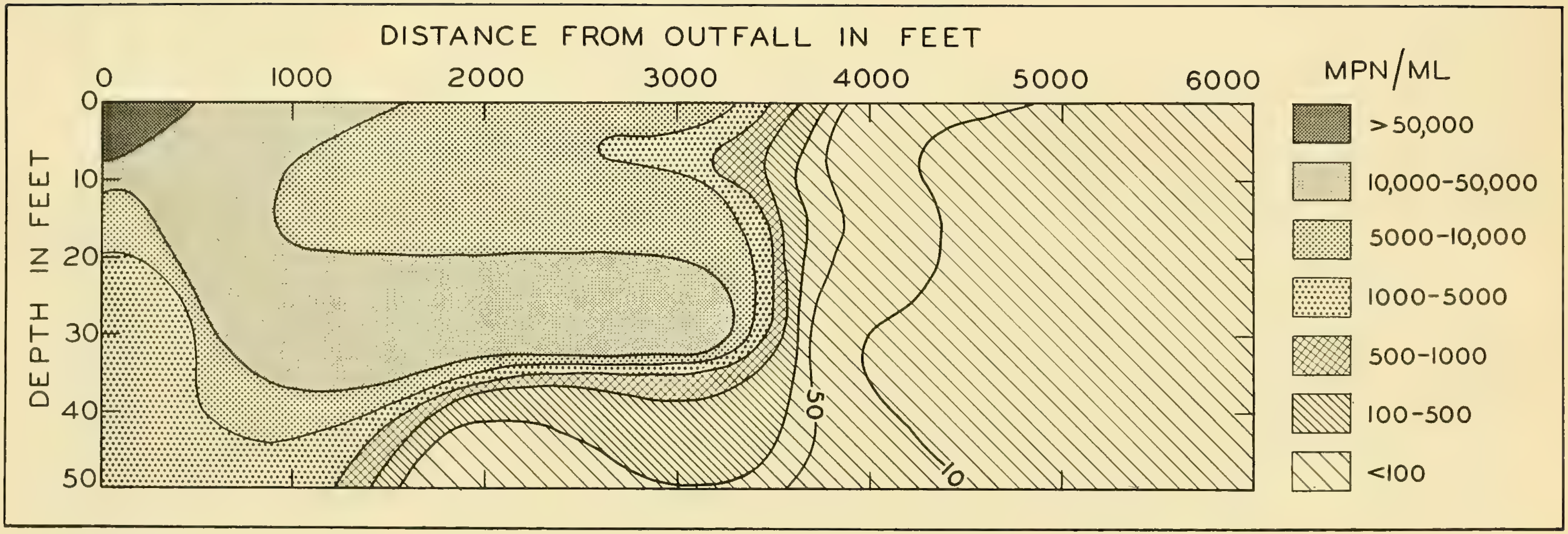
Bacterial profile extending parallel to shore in the waters surrounding the Hyperion sewer outfall on January 12 and 13, 1956.



COLIFORMS MPN/ML AT HYPERION

Figure 14

Vertical distribution of coliforms independent of direction in the waters surrounding the Orange County sewer outfall on December 19 and 20, 1955.


DISTANCE FROM OUTFALL IN FEET
0
1000
2000
3000
4000
5000
6000
DEPTH IN FEET
0
10
20
30
40
50
50
10
MPN/ML
>50,000
10,000-50,000
5000-10,000
1000-5000
500-1000
100-500
<100

data from Orange County, in which the MPN are shown against distance and depth, but independent of direction. The tongues cannot represent a subsurface flow of sewage away from the outfall for several reasons. The most compelling of these is that the temperature and chlorinity of the water in the tongues are characteristic of the normal sea water in the area rather than being characteristic of the surface sewage-sea water mixtures that have similar coliform populations. Even if the profiles are greatly distorted because of insufficient data, the finding of even individual high subsurface counts in areas of normal chlorinity can only be explained by assuming that the liquid and solid phases of sewage move differently after being discharged into the ocean. The main, if not only, differential force acting on the two phases is that of gravity and the high subsurface counts are almost certainly due to sedimentation of particulate material.

Although most of the profile results can be explained in this fashion, the results obtained on February 12 at Whites Point remains a mystery. On this occasion the pattern was confused with alternating highs and lows, with the highest count of all being found some 12,000 feet up coast from the boil at a depth of 65 feet.

Coliforms in Bottom Sediments

In the First Quarterly Report, mention was made of the detection of coliform bacteria in the sediments over a large area surrounding the Hyperion outfall. At that time it was the authors' understanding that there had been no large scale introduction of coliforms into the area for a period of over a year, and the question arose as to whether the organisms found were indeed coliforms and

if so, whether they represented survivors of those introduced a considerable time ago. As a consequence, their occurrence in the Hyperion area was reinvestigated and exploratory work was done in the vicinity of the Whites Point and Orange County outfalls.

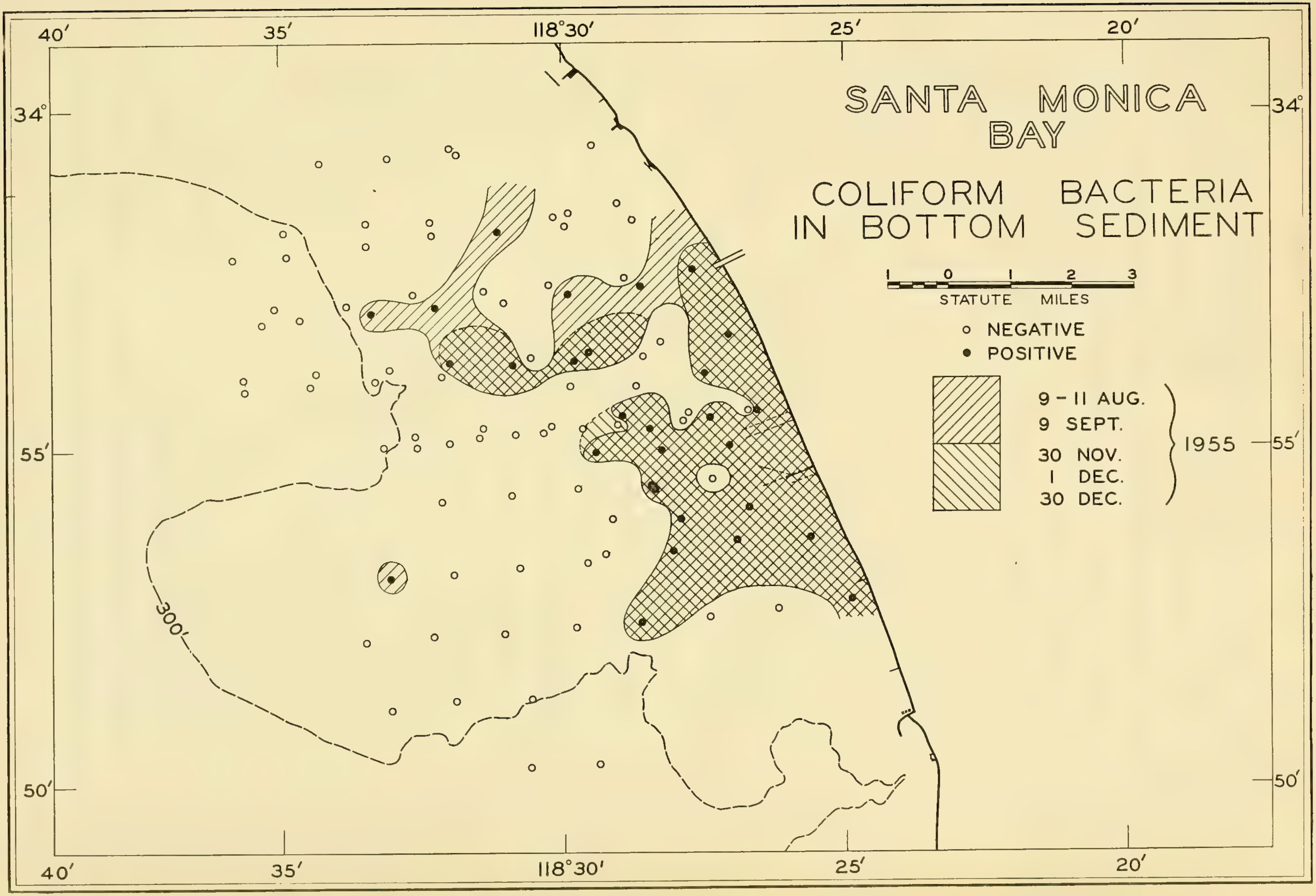
Some 70 samples were collected in Santa Monica Bay covering essentially the same area previously investigated. The area in which positive samples were found in either the present or previous survey is outlined in Figure 15. In general, the extent of the field appeared about the same on both surveys and the numbers of coliforms found in the sediment samples were similar. All typical colonies picked from positive confirmed plates proved to be coliforms by the Imvic test and morphological examination. All tetrathionate enrichment broths set up for the detection of enteric pathogens proved negative.

The counts made on sediments collected in the vicinity of Whites Point and Orange County outfalls have been quite variable. Samples from essentially the same location have shown high counts on one occasion and low counts on another. In a series of four cores taken one after the other near the Whites Point outfall making every effort to sample the same location, surface counts of nil, 6, 23, and 23/gram wet weight were obtained. This range is not excessive and coincides with the range given by three separate samples taken from one of the same cores. On the other hand, two samples taken near the Orange County boil gave counts of nil on one occasion and of 10,000/gram on the other.

The sampling procedures used for the sediments are now believed to be grossly inadequate for the following reasons. It can be assumed that the majority of the coliforms occur in a

Figure 15

Distribution of coliform bacteria in the bottom sediments in the vicinity of the Hyperion outfall.


SANTA MONICA BAY
COLIFORM BACTERIA IN BOTTOM SEDIMENT
1 0 1 2 3
STATUTE MILES
NEGATIVE
POSITIVE
9 - 11 AUG.
9 SEPT.
30 NOV.
1 DEC.
30 DEC.
1955
300′
40′
35′
118°30′
25′
20′
34°
55′
50′

very thin layer or film at the sediment surface which should be fairly fluid and mobile. When samples are taken with a snapper, it is probable that this layer is disturbed both during the actual collection and also by the washing received during retrieving the snapper through the water column. When samples are taken with a corer, this surface layer usually remains intact until the core is removed from the barrel at which time considerable distortion can occur. In either case, when the sample is taken for analysis, variable proportions of the surface and subsurface layers are included and results will not be comparable nor will they express the maximum surface populations. For the future program dealing with this problem, a new type of sampler has been devised that captures the entire surface layer of a given area of sediment. If the total sample is then used for preparing the required dilutions, one would determine the coliforms per unit surface area which is the key parameter in this problem.

Because of the sampling difficulties, it is believed that the counts obtained in the various sediments are minimum counts and that much higher populations may occur in a thin surface layer. Whatever the quantitative difficulties inherent in the data, there is no doubt that the organisms detected are true coliforms of sewage origin and not peculiar marine bacteria that happen to give positive confirmed tests. Whether the detected coliforms have survived in the sediments for long periods of time or whether, alternatively, they are of recent deposition cannot be decided. There are certainly enough coliforms in the solids settling from the Whites Point and Orange County outfalls to account for the observed sediment population in those localities.

The same is probably true around the Hyperion outfall since the data now available on the chlorinated effluent routinely discharged indicate large coliform populations may survive the chlorination. It is reassuring, however, that none of the 70 samples tested were at all suspicious of enteric pathogens.

Fate of Coliforms

Considering only the data presented so far, the interpretation of the results appears straightforward. It has been shown at all three outfalls that the effect of dilution on reducing the coliform count is very slow after the initial mixing of the effluent with sea water in the immediate vicinity of the outfalls. Initial dilutions of the sewage as low as one part in 35 at the surface have been calculated from chlorinity data at Whites Point where diffusers are used, and indications are that most of the sewage reaches the surface without appreciably greater mixing. It appears safe to conclude that a similar situation would exist at the proposed outfall, that the entire volume of water in the bay would not be available for mixing, and that dilution by itself would not reduce the coliform population to a point where State standards are met.

It has been demonstrated that at all three outfalls, factors other than dilution cause a significant disappearance of coliforms from the surface waters. One of these factors has been clearly shown to be the process of sedimentation. It is our qualitative impression that no other factors beside dilution and sedimentation are of significance in the disappearance of coliforms over the initial six hour period after discharge of the effluent. Unfor-

tunately, because of the highly variable composition of the sewage effluents and the impossibility of analyzing a sufficient number of subsurface samples to give an exact quantitative picture, one cannot calculate whether the extra disappearance of coliforms above dilution is due entirely to the sedimentation process or whether death and other factors also play a significant role. In this connection, beach count data around the Hyperion outfall clearly indicate survival of coliforms for greater than 24 hours. For purposes of prediction, however, the causes of disappearance are secondary as long as the rate of disappearance can be estimated.

The rate of disappearance for all causes in the vicinity of the Orange County Outfall is such that counts of more than 10 coliforms per ml should not occur at distances of greater than six hours travel from the outfall. The surface distribution of coliforms at Orange County and the observed rate of travel of the dye patches, as well as other data, indicate that currents of 0.2 knot or less are typical for the area, giving a pollution boundary of 10 coliforms per ml at roughly 6,000 feet from the outfall. Since the dominant direction of sewage flow observed in this area has in general been parallel to the beach rather than towards the beach, little pollution would be predicted for the beaches in the vicinity of the Orange County outfall and what does occur would be expected within roughly a mile on either side. Actually, the beach count data available do not bear out these predictions. The possible reasons for this discrepancy will be discussed in the following section.

If the rate of disappearance of coliforms in the Orange County area also held for the proposed outfall in Santa Monica Bay, then

one would predict from the oceanographic data available, that there would be an ample margin of safety against beach pollution. The extra volume of sewage to be discharged increases the coliform load by roughly one and one half magnitudes. Since the overall disappearance curve is exponential rather than arithmetic in character, the extra load would mean an increase of only about two hours for the counts to fall below the 10 per ml level, all other factors being equal.

The dye patch data suggest that the rate of disappearance is not the same at the three outfalls, although the rates did not differ markedly between Orange County and Hyperion. If the disappearance curves for Hyperion and Whites Point in Figure 3 are extrapolated, they intersect the 10 per ml level at about 7 hours and 10 hours, respectively. Since the curves are based on single runs, these exact times cannot be taken too seriously. However, the slower disappearance of coliforms in these two areas, in the order given is also supported by the surface distribution, including the data from the two grids run at Hyperion. The "viability" studies done by the Los Angeles Sanitation District indicate a much slower disappearance around the Hyperion outfall as compared to either the rate we calculate from our dye patch experiment or to the rate around the Orange County outfall. The questions as to which rate should be used for estimating the situation that would exist around the proposed new outfall is discussed later.

Orange County Beach Count Data

The beach data in the vicinity of the Orange County outfall shows that coliform counts (from the Orange County Sanitation District) in excess of ten per ml occur fairly frequently and

that on occasion the State standard of not over ten per ml in 20 per cent of the samples is exceeded. The area of excess counts extends from about 3,000 feet down coast to 15,000 feet up coast from the outfall. If the morning and afternoon samples are considered separately, the picture differs somewhat in that the polluted area is more restricted in the afternoon and extends farther upcoast in the morning (Fig. 16).

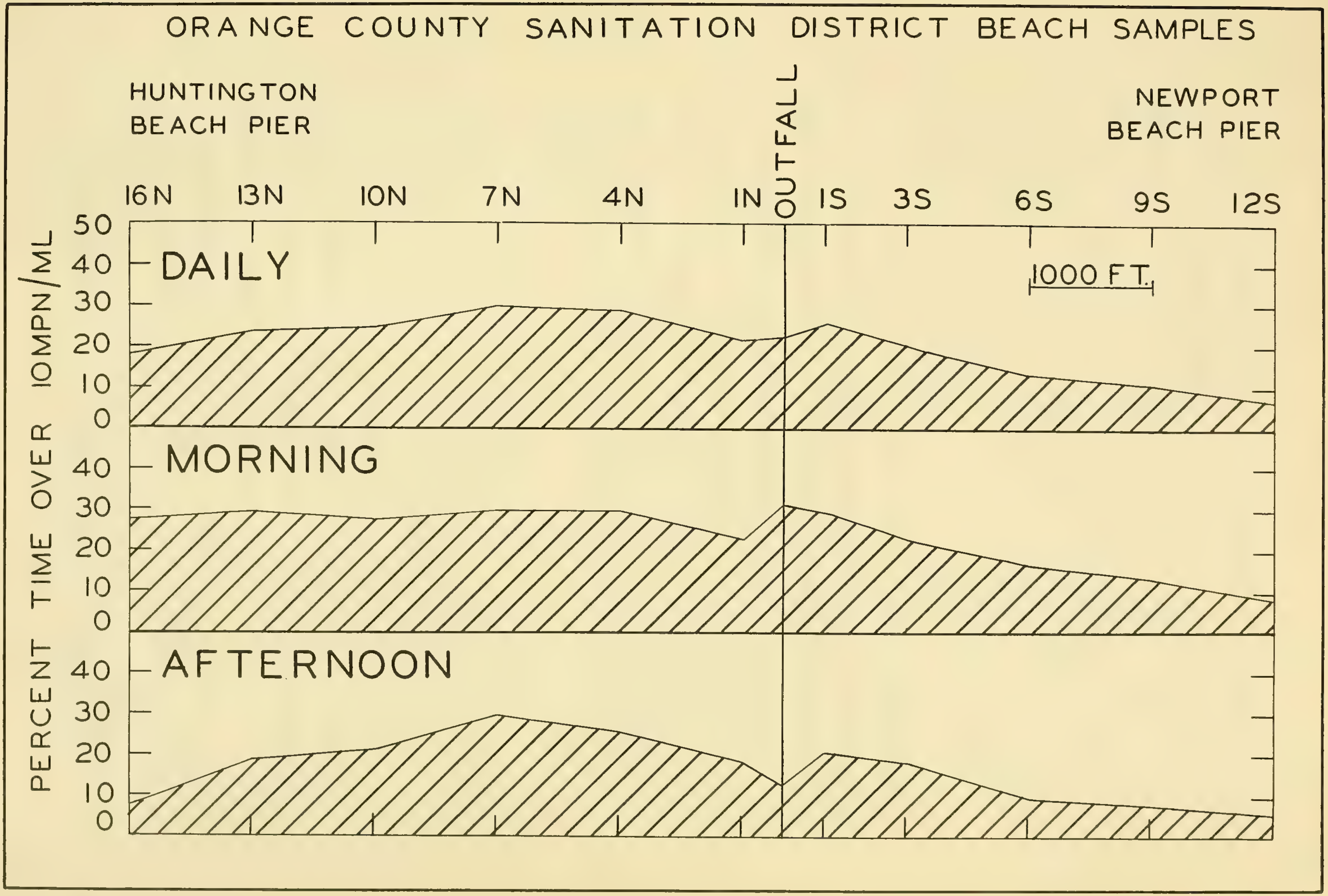
Contrary to what one would expect from the coliform distribution observed in the ocean, the area of excessive counts did not show a peak within the beach zone less than 6,000 feet from the outfall. This is particularly surprising because on at least one occasion a dye patch experiment showed that the sewage field could reach the surf zone in a period of three hours. The occurrence of excessive coliforms on the beach over 15,000 feet away from the outfall is also incompatible with the conclusion that the coliform field does not extend for more than 6,000 feet from the outfall.

Assuming that the dye patch and profile experiments give a representative picture of the coliform field in the ocean on the days of the experiments, and there is no reason to believe otherwise, several explanations may be offered for the discrepancies between the beach and ocean distribution. First, and least probable, is that the observed beach counts are due to "bootleg" sewage introduced at points upcoast from the outfall. A check of the area failed to show any source of sewage of sufficient magnitude to be responsible.

The second possibility is that high beach counts occur only on days when unusual conditions exist. If, for example, currents

Figure 16

Beach counts along the Orange County coast exceeding 10/ml from August through November, 1955.



ORANGE COUNTY SANITATION DISTRICT BEACH SAMPLES
HUNTINGTON BEACH PIER
NEWPORT BEACH PIER
OUTFALL
16N
13N
10N
7N
4N
1N
1S
3S
6S
9S
12S
1000 FT.
DAILY
MORNING
AFTERNOON
PERCENT TIME OVER 10MPN/ML
50
40
30
20
10
0

of a half knot velocity or more occur periodically, the sewage field could be carried 15,000 feet in six hours and thus bring excessive coliforms into the beach areas as observed. This supposition could be checked if there were some pattern from which times of excess counts could be predicted. Unfortunately, no such basis exists, and it would probably be necessary to make many trips of the type already carried out until one, by coincidence, happened to coincide with a day of excessive beach counts.

An alternate possibility of the unusual conditions hypothesis is that the character of the sewage effluent alters in sedimentation characteristics from time to time so that the extra disappearance of coliforms over and above dilution is retarded or eliminated. It is obvious that the longer the suspended solids remain on the surface, the farther the sewage field can extend. The authors do not have sufficient knowledge of the characteristics and variations in the Orange County sewage to know whether this alternative has any validity.

A third possibility is that the high beach counts are correlated with periods of excess plankton in the inshore waters. There is some evidence in the literature that coliforms may be associated, mechanically or otherwise, with plankton and thus be more widely distributed as the plankton are transported through the water. At the moment, there is little relation evident between the available plankton data and the beach counts.

Fourthly, it is possible that the coliforms, once reaching the surf zone, are carried upcoast by a longshore drift. This idea is based on the supposition that sedimentation is a major factor in the disappearance of coliforms and that die-off is a minor one

over short periods of time. It can be assumed that once the suspended matter reaches the surf zone no further sedimentation will occur. Consequently, coliforms brought into the surf would then disappear only by dilution of slow die-off. With an upcoast drift, material brought into the beach less than 6,000 feet away from the outfall could be transported greater distances away. How rapidly coliforms would disappear would then depend on dilution and whether a diminution from this factor or others occurs is not known. It would appear that an investigation of the fate of coliforms in the surf zone is a necessary step in understanding the situation at Orange County.

Finally, it may be that the coliform counts on the beach are not directly related to the sewage being discharged, but instead are determined by the distribution of coliforms in the bottom sediments. It is conceivable, from the scattered data obtained, that the bottom has a high coliform content for a large area surrounding the outfall. If this field of coliforms extends inshore for a sufficient distance, it is possible that any oceanographic condition that stirs up the bottom will result in a fresh introduction of coliforms into the water along the beach. One would expect from this hypothesis that a correlation should exist between beach counts and local wave action. More complete information is required on the extent of the bottom coliform field before this possibility can be properly evaluated.

In summary, although the beach count data do not correlate exactly with the predictions from the dye patch experiments, the discrepancies can be explained without discarding the observed rate of disappearance as being typical for the average conditions around the outfall.

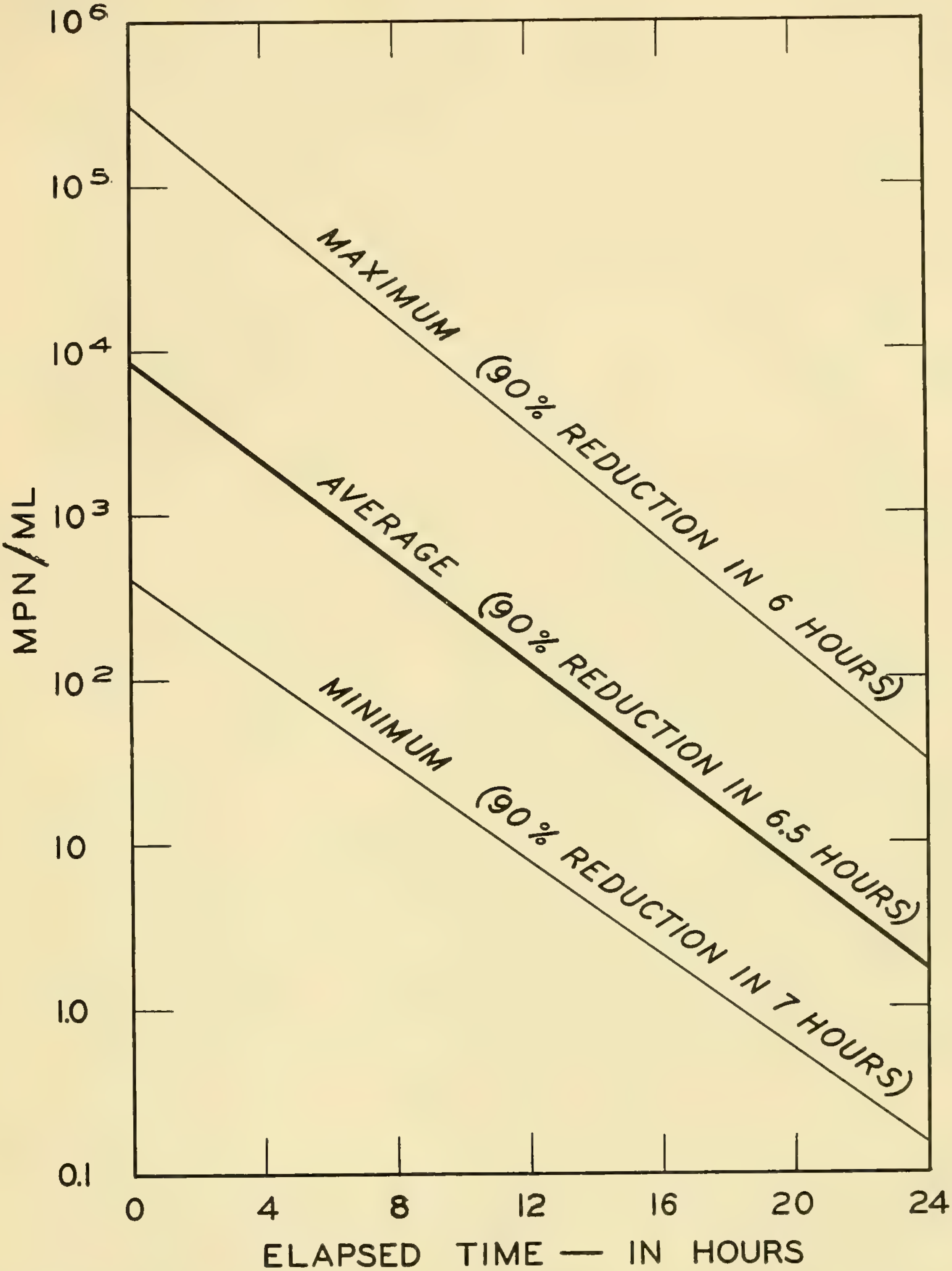
Los Angeles Sanitation District Data

The personnel of the Los Angeles Sanitation District have been conducting "viability" studies on coliforms discharged at periodic intervals in the unchlorinated secondary effluent of the Hyperion Plant. Their data are interpretated as showing a much slower rate of disappearance of coliforms than was observed in the dye patch experiments of the Hancock Foundation. Figure 17 is based on a composite of the data of the LASD experiments and indicates that roughly a 6.5 hour period is required to give a 90% reduction of the initial boil count and a 24 hour period to reduce the count to the 10 per ml level. As is described below, the field techniques they used in their experiments differ from those we employed. Since their rate of disappearance differs so markedly from ours, several questions arise. First, are the differences in methods employed responsible for the differences in results? If so, which method is superior for estimating disappearance rates and which, if any, should be the basis of predicting the situation around the proposed outfall? These questions will be dealt with in turn.

As already described, in our dye patch experiments a single point at the edge of the boil is marked with dye. Samples are periodically removed from the dyed area, and dye is renewed as required to follow the marked field. An effort is made to choose all samples from the most intensely dyed area of the patch and to renew the dye in this area. In the Hyperion experiments, the sewage field is marked with one or more dye patches as well as with current crosses. For each point on their disappearance

Figure 17

Average reduction of coliform densities in Santa Monica Bay. (Graph based on data obtained by the Los Angeles Sanitation District).



AVERAGE REDUCTION OF COLIFORM DENSITIES IN SANTA MONICA BAY

(BASED ON DATA OBTAINED BY LASD)

curve a traverse is made across the area defined by their markers. From 2 to 10 samples are taken on these traverses which in some instances extend over several thousand feet. The maximum count obtained on the traverse is interpreted as marking the "center" of the sewage field and decreasing counts are interpreted as meaning departure to varying degrees from the main field. The line shown in Figure 17 is an approximate "best fit" drawn through the medians of their disappearance values at the various times of sampling and is interpreted as representing the average picture.

Apart from the differences in the nature of the experiments, there are no apparent differences in the techniques employed for determining coliforms that would account for the differences in results. Dr. Mittwer has observed the LASD techniques and Mr. Garber has observed those of the Hancock Foundation. Both are satisfied that the technqiues are essentially similar. Personnel of the AHF have usually employed five tubes per dilution in the dye patch experiments whereas the LASD have employed two tubes. Although this might make our individual determinations a little more accurate, it should not affect the general findings. We have always taken our samples from the dyed area while many of theirs were taken from areas where no dye was present. The possibility that the dye used might be toxic to coliforms was considered, but laboratory experiments failed to show any toxicity whatsoever at concentrations much higher than those present in the dye patch.

The grids run at Whites Point and at Hyperion show that large variations in coliform counts are observed in samples taken almost simultaneously over a small area of ocean surface. It was pointed

out that the variations in sewage content of the Whites Point grid were very small and the variable counts cannot be ascribed to passing in and out of the sewage field. The same is apparently true in the Hyperion area. At the same time the grids were being run, the Hyperion personnel were measuring "viability" according to the described procedure. Their two hour traverse had three points within the area of the first grid, and their 4.7 hour traverse had four points within the grid area. The counts for these seven determinations are shown in Table 9, along with other pertinent data. It can be seen that the variations in count cannot be ascribed to variations in sewage content. It also can be seen that traverse A and B taken by themselves indicate a marked reduction in count over the period involved, but that the results from the grid over essentially the same period do not indicate this decrease. If one takes the zero time count on the same day and the two traverse averages, a marked decrease is observed that approximates the results of our dye patch experiments, i.e., 0 hours - over 70,000/ml, 2.0 hours - 22,000/ml, and 4.7 hours - 3,000/ml. Thus, data can be chosen from their runs that gives a picture almost identical to ours.

The conclusion from this discussion is that both methods are measuring the same thing; that is, the disappearance of coliforms in the individual patches of the sewage field that happened to be sampled. Neither is presenting a picture of what happens in a representative sample. Either will determine what should happen on the average, and both should give essentially similar results if equal numbers of samples are examined by both methods. These conclusions are reinforced by the data obtained when LASD personnel

TABLE 9

A COMPARISON OF DATA FROM TRAVERSES

CROSSING TWO GRIDS WITH THE GRID DATA

Station	MPN	CI o/oo	Calculated % Sewage
Traverse A - 11:51	6,200	18.01	2.9%
11:52	70,000	17.90	3.5%
11:53	24,000	17.62	5.0%
Geometric Av.	22,000		
Traverse B - 14:29	230	18.07	2.6%
:30	2,300	18.03	2.8%
:31	6,200	18.13	2.2%
:32	24,000	17.72	4.5%
Geometric Av.	3,000		
Grid #1 11:27 to 11:40			
Geometric Av.	3,100		
Grid #2 13:59 to 14:12			
Geometric Av.	3,300		

used their procedure in the vicinity of the Orange County outfall. Their results were identical with those of the AHF. Since they have run many experiments around the Hyperion outfall and we have run only one, it is probably that their results give a better average picture than ours.

The question then remains as to whether their disappearance time should be used as a basis for predicting the situation around the proposed outfall, and the answer to this is probably no. It can be taken as established that the disappearance curves around the three outfalls differ. The cause of the difference is apparently not the differences in volume of sewage being discharged at the three outfalls; for if this were the case, one would expect the order of disappearance to be Orange County, Whites Point, and Hyperion. Nor is it the difference between primary and secondary treatment, since then one would expect Whites Point and Orange County effluents to give similar results. If it were a question of a difference in outfall construction, diffusers as against a single point discharge, one would expect the Whites Point area to show the greatest rate of disappearance because of the higher initial dilution. The two remaining possibilities are that different rates of disappearance relate either to differences in the oceanographic conditions in the areas, or else to differences in the nature of the material being discharged. Although the Whites Point area is quite different oceanographically from the other two, there are no known conditions that suggest that Orange County and Hyperion should differ appreciably. On the other hand, field and laboratory data show that the effluents from the three outfalls differ markedly.

Qualitative field observations suggest that there is a great difference in the character of the solids being discharged and in particular that these solids have markedly different settling properties. Particulate material from the effluent is visible in the boil of the Orange County outfall as small black discreet particles usually less than 1/4 inch in diameter. The particles rapidly diminish in number until at a distance of about 1,000 feet, few are noticeable in the surface waters. Strings or patches of grease are rarely seen in this area and when such surface clots do occur, they are small and minor in extent.

From the Hyperion outfall there are on most occasion large flat flocculent particles, often an inch or more in diameter in the boil and the immediate waters. The particulate material is frequently in such great quantities as to reduce the transparency to less than 2 feet with the Secchi disc and less than 1% light transmission with the transparency meter. The black floccules may remain visible in the surface layers for distances exceeding two miles, becoming consistently smaller with distance from the outfall. Although surface films of grease are not common in the waters surrounding the Hyperion outfall, they occur with greater frequency than in the Orange County area and may cover several hundred square feet of water surface. Such patches have been noted as far as ten miles from the outfall.

Particles in the sewage discharged from the Los Angeles County outfall at Whites Point are similar to those seen in the Orange County area, except for the frequent occurrence of floatable objects. Large floccules are not particularly obvious, nor are they visible at great distances from the boil. However, the

surface of the sea around this outfall is usually covered with large continuous patches of brown grease and stringy material. These patches may be several thousand feet in length and many hundred feet wide. Grease areas covering several hundred square feet have been seen as far as six miles from the outfall site.

It appears, therefore, that each type of effluent will have its own settling characteristics and that this parameter will largely control the rate of coliform disappearance, over the periods of time significant in a disposal situation. Consequently, it is no more valid to predict what will happen in the proposed outfall on the basis of the Orange County effluent than it is on the basis of the secondary treatment effluent now being discharged in the bay. What is now needed is a study of what happens when Hyperion primary is introduced and this study should employ not only the methods already in use by our group and the Hyperion group, but should also employ radioactive tracing of the sewage field, if possible.

CONCLUSIONS

1. The greatest effect of dilution on the disappearance of coliforms occurs during the initial mixing of the effluent with sea water, and subsequent effects are minor.

2. Factors other than dilution are effective in reducing coliform numbers. Evidence has been obtained to show that sedimentation has a major role in this connection and may actually by the only other factor of significance operating over short time periods.

3. The rate of disappearance of coliforms differs at the three outfalls studied, being fastest at Orange County and slowest at Whites Point. The differences in these rates seem to be associated with the settling characteristics of the particulate fractions of these effluents.

4. It appears unwise to base any predictions of the behavior of the proposed outfall on the disappearance rates measured for the three effluents and it is proposed that similar measurements be made during discharge of primary effluent from Hyperion.